Test Facilities World Tour

Nobu Toge (KEK)

Introduction

- This talk aims to offer a quick tour of existing accelerator test facilities in the world, rather than giving a comprehensive critical review.

- For each test facility, a summary is given, in a rough order of its name, mission, layout, participants, short/mid/long-range goals and other special points to note.

- My thanks to
  - CLIC – G.Geschonke (CERN)
  - NLCTA/Klystron Test Lab – S.Tantawi (SLAC) and C.Adolphsen (SLAC)
  - CesrTA – M.Palmer (Cornell)
  - NEXTEF – T.Higo (KEK)
  - ATF – N.Terunuma (KEK)
  - ATF2 – T.Tauchi (KEK)
  - FLASH – E.Elsen (DESY), J.Cowardine (ANL)
  - NML, FNAL VTS/HTS – M.Champion, C.Ginsburg (FNAL)
  - STF – H.Hayano (KEK)

- My apologies to colleagues at institutes whose work I am not covering due to time/space constraints (in particular, Jlab, Cornell, IHEP-Beijing, INFN and Saclay for their SCRF-related efforts).

CTF3

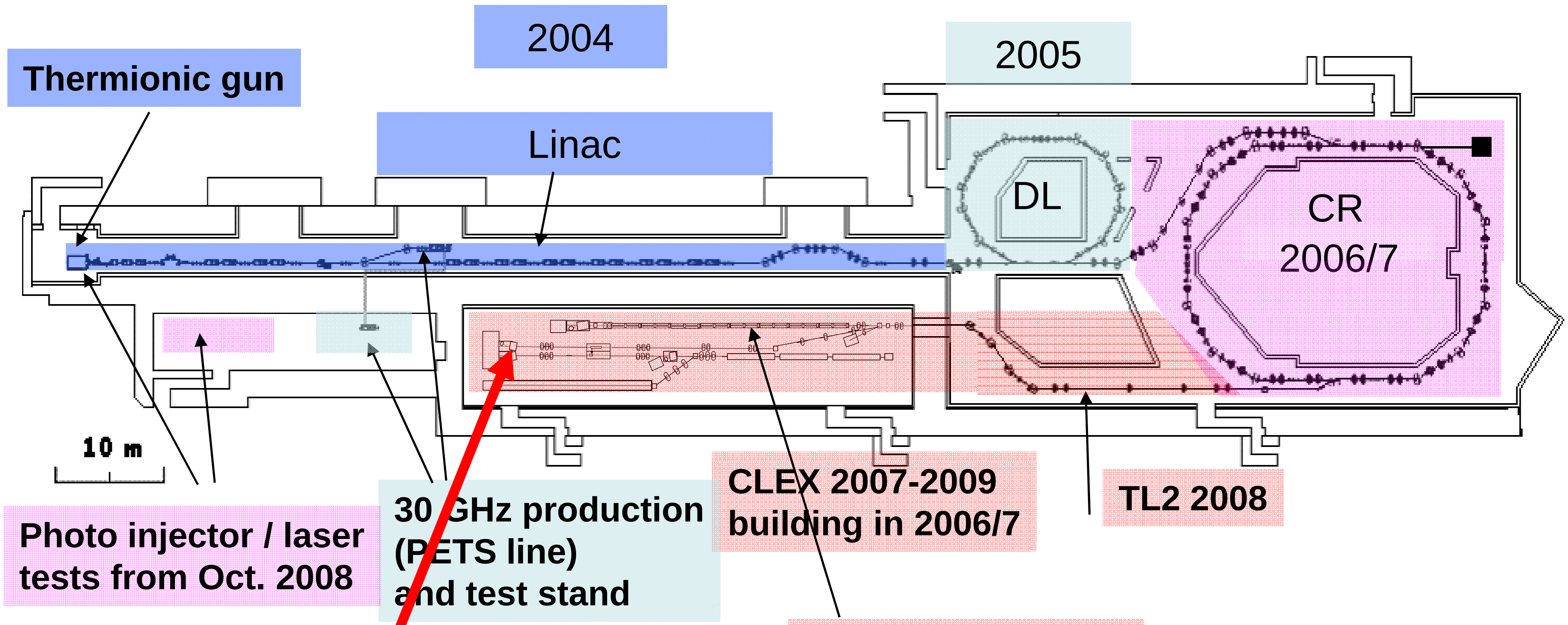
- CTF3 is
  - A test facility at CERN to provide answers for CLIC-specific issues, where CLIC CDR is to be prepared in/by 2010. Motivated by room-temperature linear colliders; especially in the TeV cm range.
  - Collaboration with participants from 24 institutes / 16 countries. In 2008, approx 30FTEs from CERN, 21 FTEs from outside CERN.

- Two main missions
  - Prove the RF power source scheme at CLIC, by demonstrating “relevant” linac sub-unit
    - Bunch manipulations, beam stability
    - Drive beam generation
    - 12GHz extraction
    - Acceleration of test beam
  - Provide RF power for validation of CLIC components
    - Acceletor structures (CAS)
    - RF distribution
    - Power extraction and transfer structure (PETS)

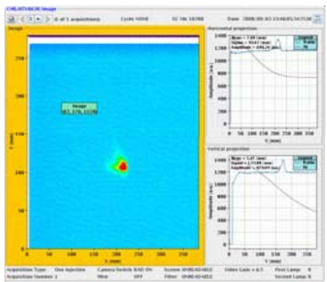
- Relevance for all linear colliders:
  - Beam-based active alignment studies in TBL
  - Vibration control of equipment in CLEX
  - Beam Diagnostics equipment – development and testing

CTF3 - Layout and Evolution

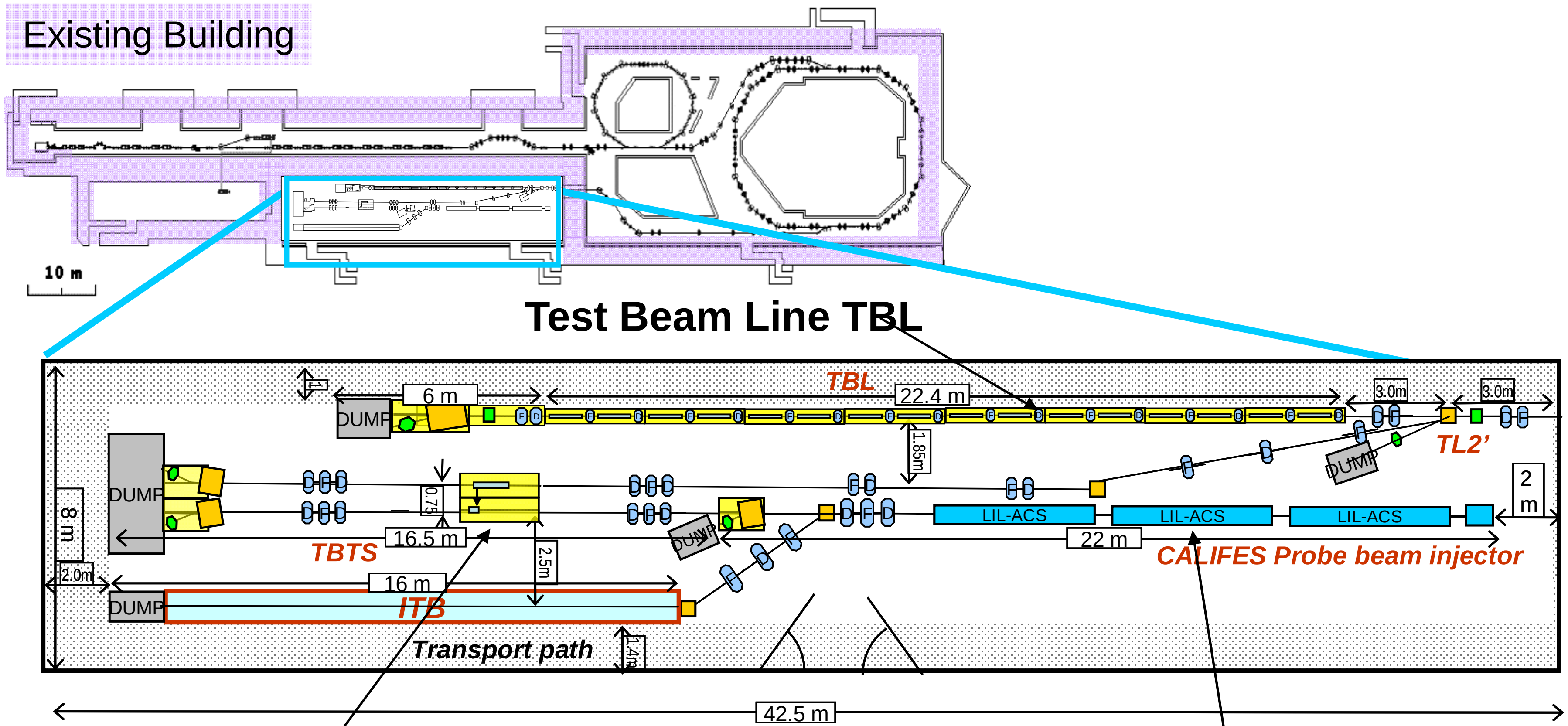
Construction in phases. All major hardware installed, except TBL



Beam up to here



CLEX (CLIC Experimental Area)



Two Beam Test Stand

Probe Beam

Construction during 2006/beg 2007
installation of equipment from
2007 - 2009

Beam in CLEX from
summer 2008 onwards

CTF3 - Research Programs

Accomplished

- Full beam-loaded linac operation - done routinely
- Phase-coded beam with sub-harmonic bunching system - done
- Bunch interleaving scheme for Drive Beam :

  Delay Loop operation - demonstrated

  Combiner Ring operation - Proof of principle, (with low bunch current)

  Isochronous optics in rings - demonstrated

Main Objectives for 2008 - 2010:

Fully commissioning of the Combiner Ring

Operate full system to generate nominal CTF3 Drive Beam (about 30 A in 140 ns)
(phase-coded beam, fully loaded linac, bunch interleaving in Delay Loop, factor 4 combination in Combiner Ring)

\+ Extract 12 GHz RF power from Drive Beam

\+ Accelerate Probe Beam with CLIC accelerating module

Install and operate Test Beam Line with multiple deceleration sections

and many other topics.........

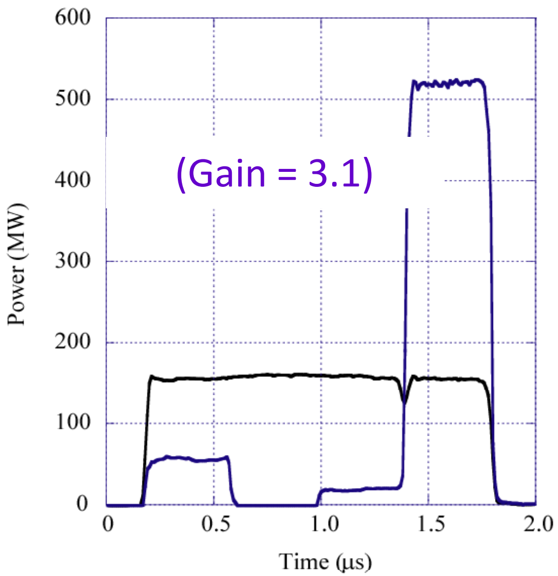
NLCTA - Mission

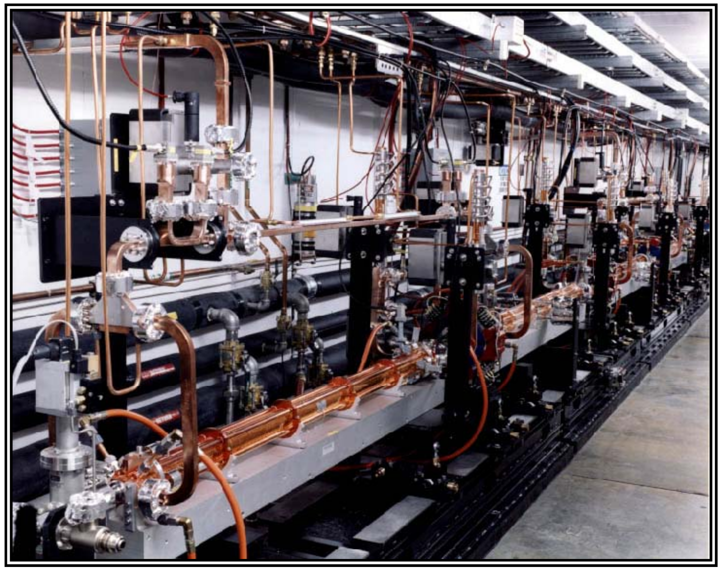
- NLCTA is
  - An accelerator test facility at SLAC, with a strong focus on operational aspects of high-power RF sources and high-gradient accelerator structures with X-band technologies.
- NLCTA missions are
  - To facilitate the development, testing and validation of system operations aspects of advanced accelerator technologies with X-band.

NLCTA – Layout

- 3 x RF stations
  - 2 x pulse compressors (240ns - 300MW max), driven each by 2 x 50MW X-band klystrons
  - 1 x pulse compressors (400ns – 300MW /200ns – 500MW variable), driven by 2 x 50MW X-band klystrons.
- 1 x Injector: 65MeV, ~0.3 nC / bunch

- In the accelerator housing:
  - 2 x 2.5m slots for structures
- Shield Enclosure: suitable up to 1 GeV
- For operation:
  - Can run 24/7 using automated controls



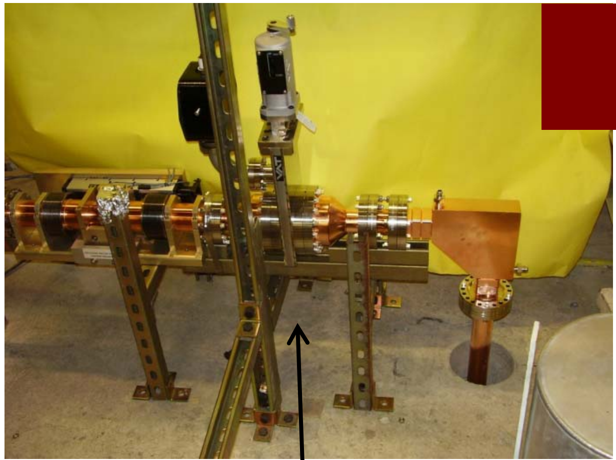


Klystron Test Lab - Mission

- Klystron Test Lab at SLAC is
  - An ensemble of test stations at SLAC with a strong focus on component-level testing of novel hardware equipment of X-band technologies.
- Klystron Test Lab missions are
  - To support the development, testing and validations of new HW components with advanced accelerator technologies of X-band.

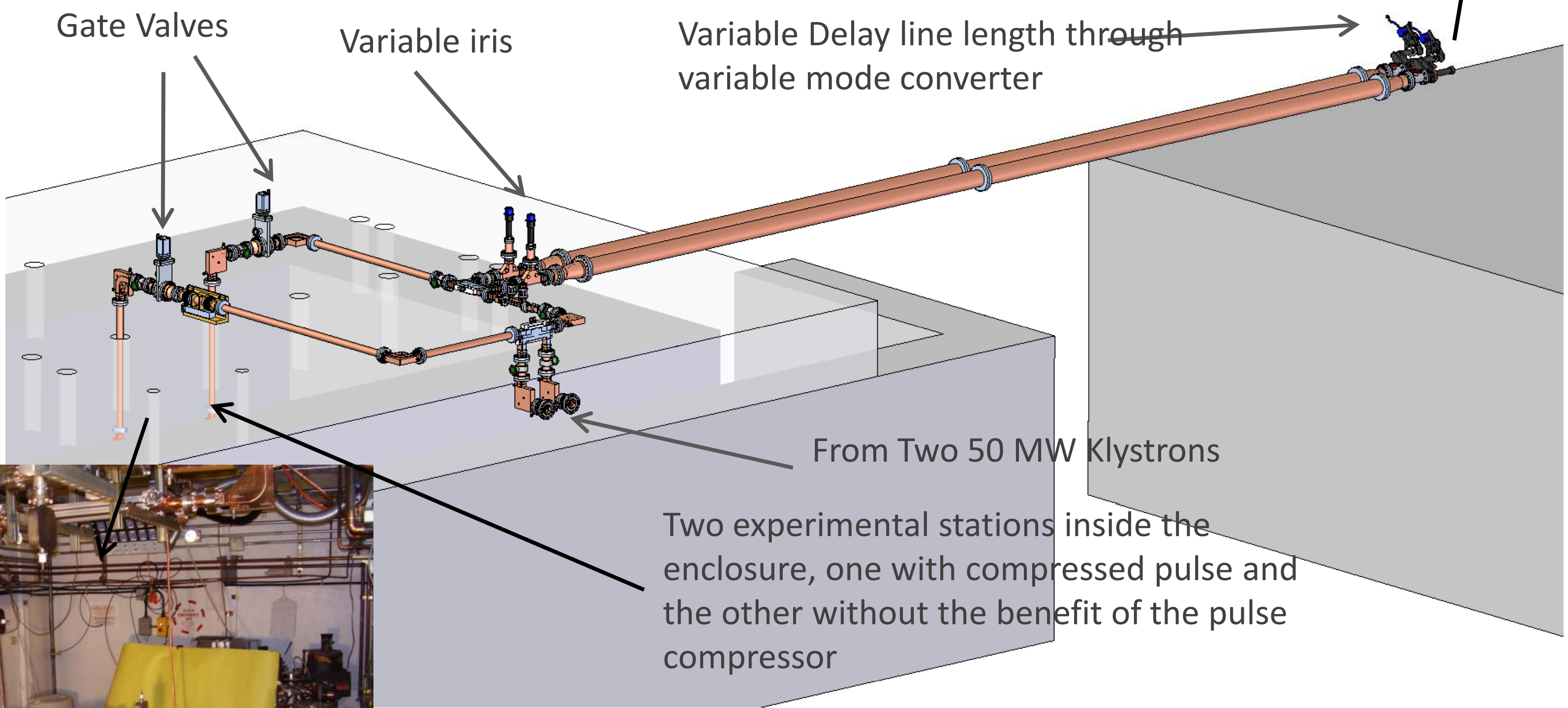
Klystron Test Lab - Elements

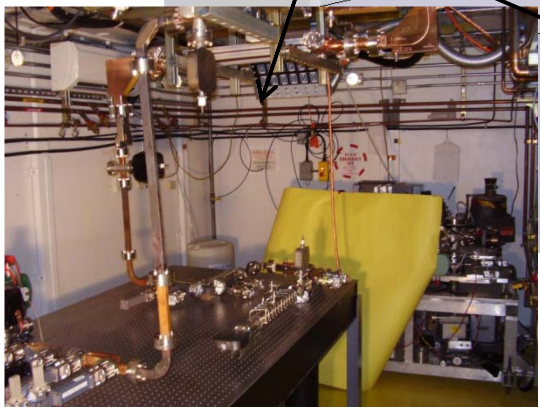
- 4 x RF Stations
  - Stations #6 and # 8 = ASTA
    - 2 x 50MW 1.5 µs klystrons.
      - With a variable compressor (63ns / 132ns / 264 ns), or through a simple addition, they can produce: “100MW 1.5 µs” ~ “550MW 63 ns” and feed two exp outputs in an enclosure that can run concurrently.
      - Cost-effective testing due to versatility and new design of a gate valve (A.Gudiev)
  - Station #4
    - 1 x 50MW 1.5 µs klystron
      - Dedicated to testing of standing-wave structures
      - Stand-alone shielding enclosure
  - Stations #2
    - 1 x 50MW 1.5 µs klystron
      - Dedicated to testing of pulsed-heating
      - No shielding



ASTA RF system

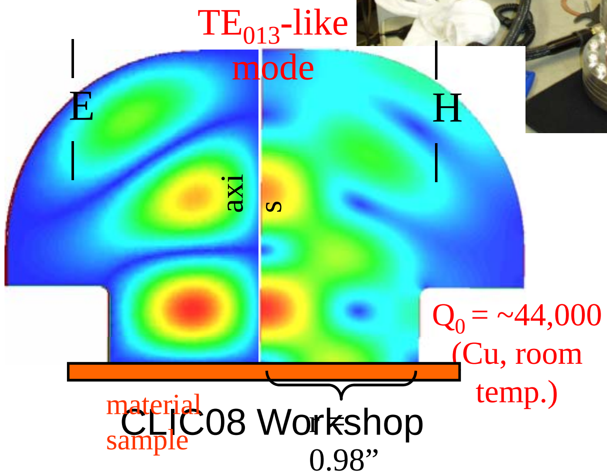
- Designed for economical testing of TW, SW accelerator structures, and waveguides.
- Versatile structure for future applications
- Will be retrofitted with an electron gun to test gradients within a year
- Wil find other applications and may be demanded for other applications (may be not related to high gradient work)

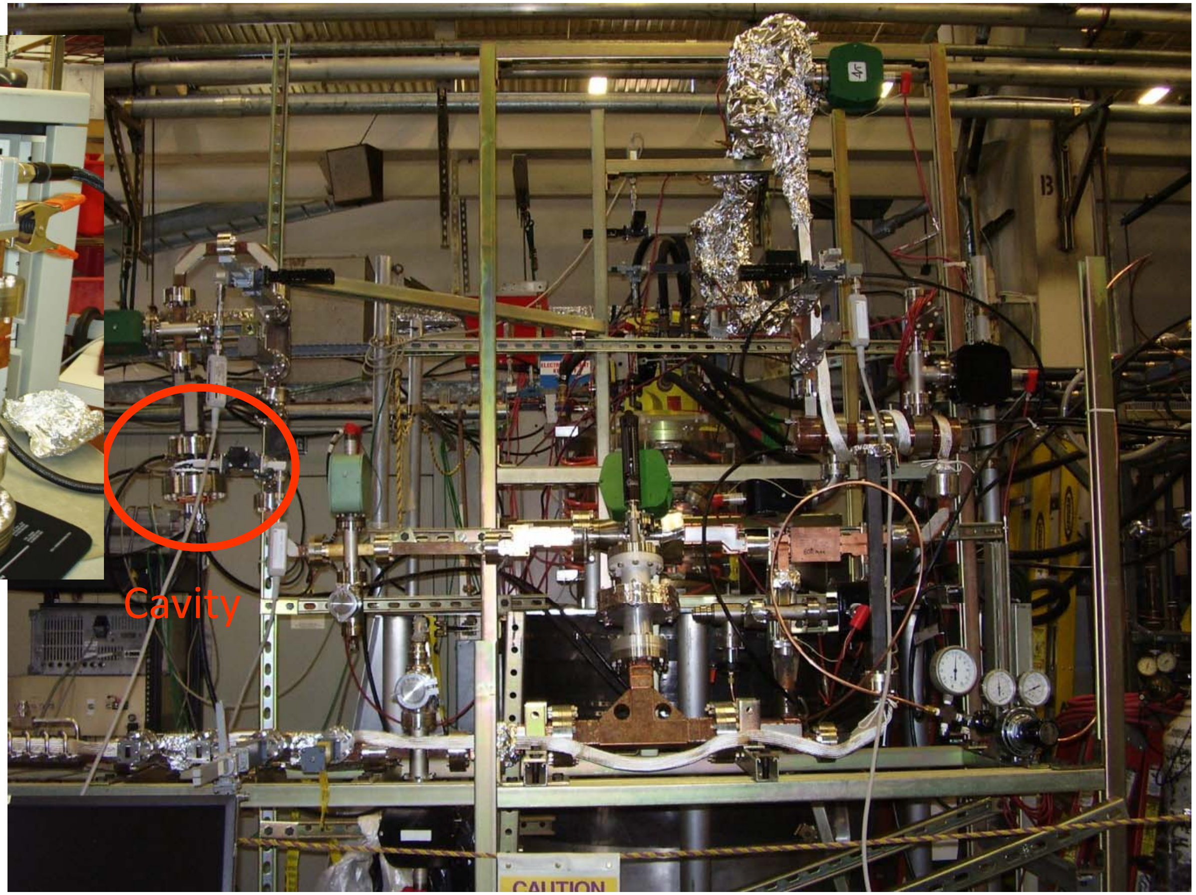




Station #4 (Pulsed Heating)

- Station 2 at the klystron test lab, a dedicated 50 MW Klystron station for material testing
- Will be retrofitted with a closed cycle cryocooler to be able to perform tests from room temperature to 4.2K



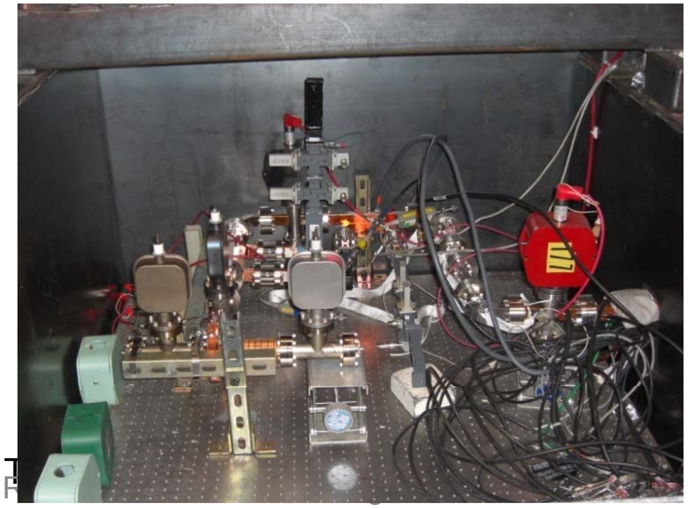


Station #2 (Stading Wave Struc.)

- A dedicated station with one 50 MW klystron
- A shielding enclosure built specially for testing short accelerator structure
- Very productive due to international participation(SLAC, KEK and frascatti structure testing program.

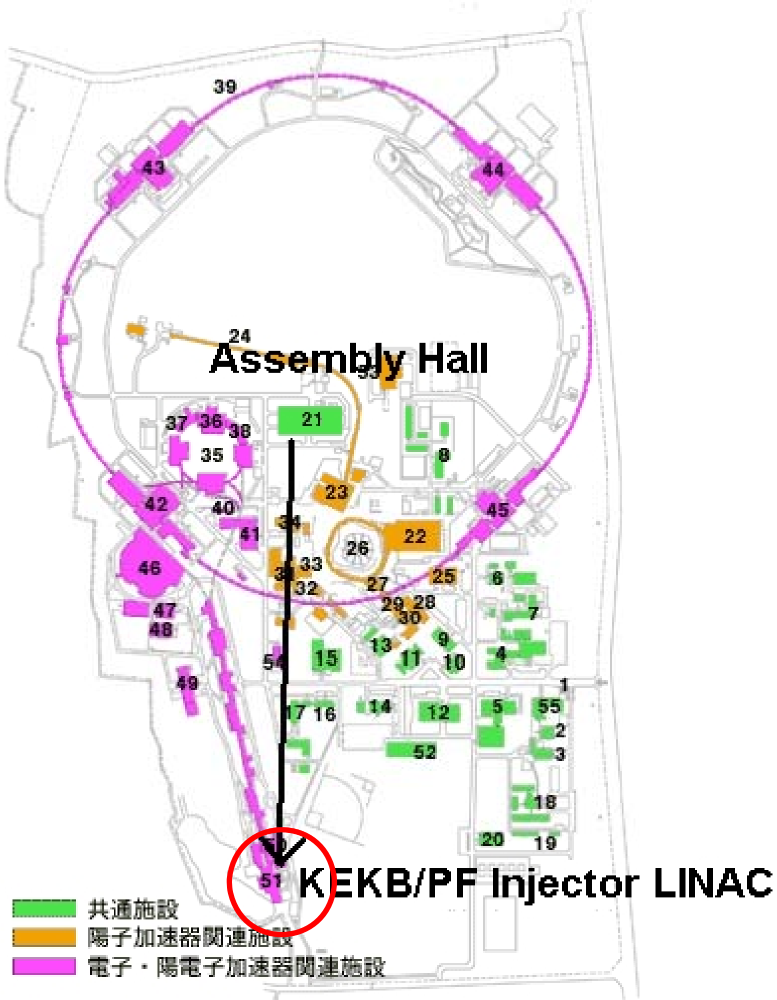
Dr. Yasuo Higashi and Richard Talley assembling Three-C-SW-A5.65-T4.6-Cu-KEK-#2

The structures are housed inside an a dedicated lead inside box suitable for up to 5 MeV



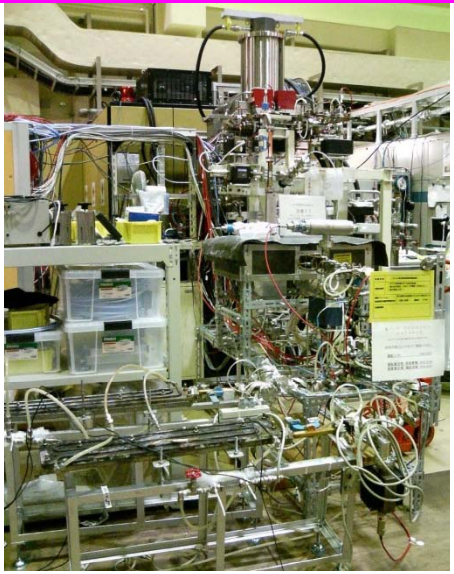
NEXTEF - Mission

- NEXTEF - NEw X-band TEst Facility at KEK
  - Is a test facility for generic R&D efforts on the high-gradient room-temperature accelerator technologies,
  - With the equipment moved from KEK assembly hall to an exp area at the south-end of the KEK injector linac.
- Main Mission
  - Continue generic basic R&D of X-band RF-related studies with emphasis on normal conducting high gradient acc structures.

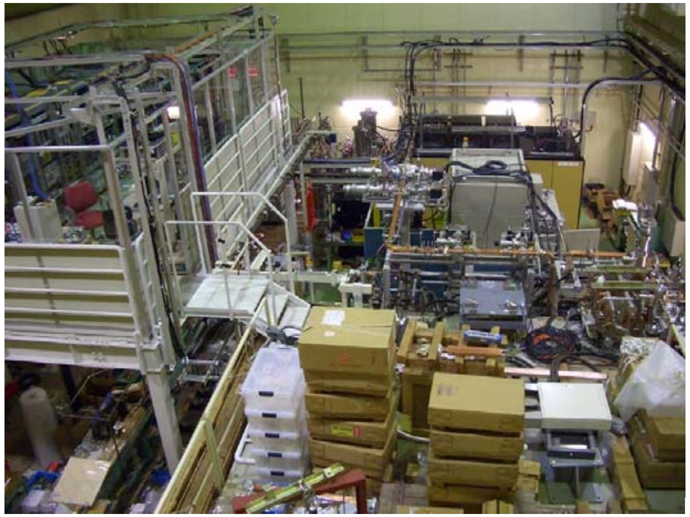


NEXTEF - Layout

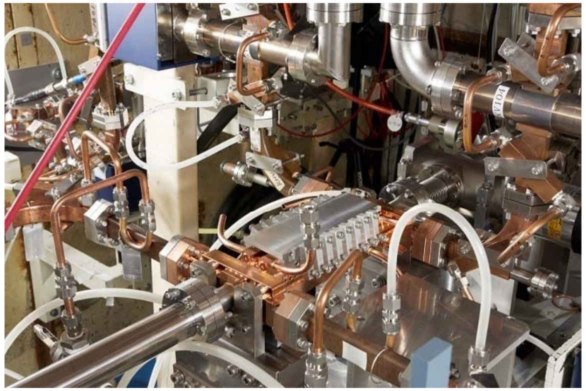
- Presently,
  - Two klystrons with a power combiner.
  - Max. 120MW/300ns, Typical. 100MW/300ns at comb.-out;
  - ~70MW/300ns at struc.-in
- Hoping to implement in 2010 (or later)
  - Pulse compression to make power of ~150MW available.



One klystron setup



Two klystron facility

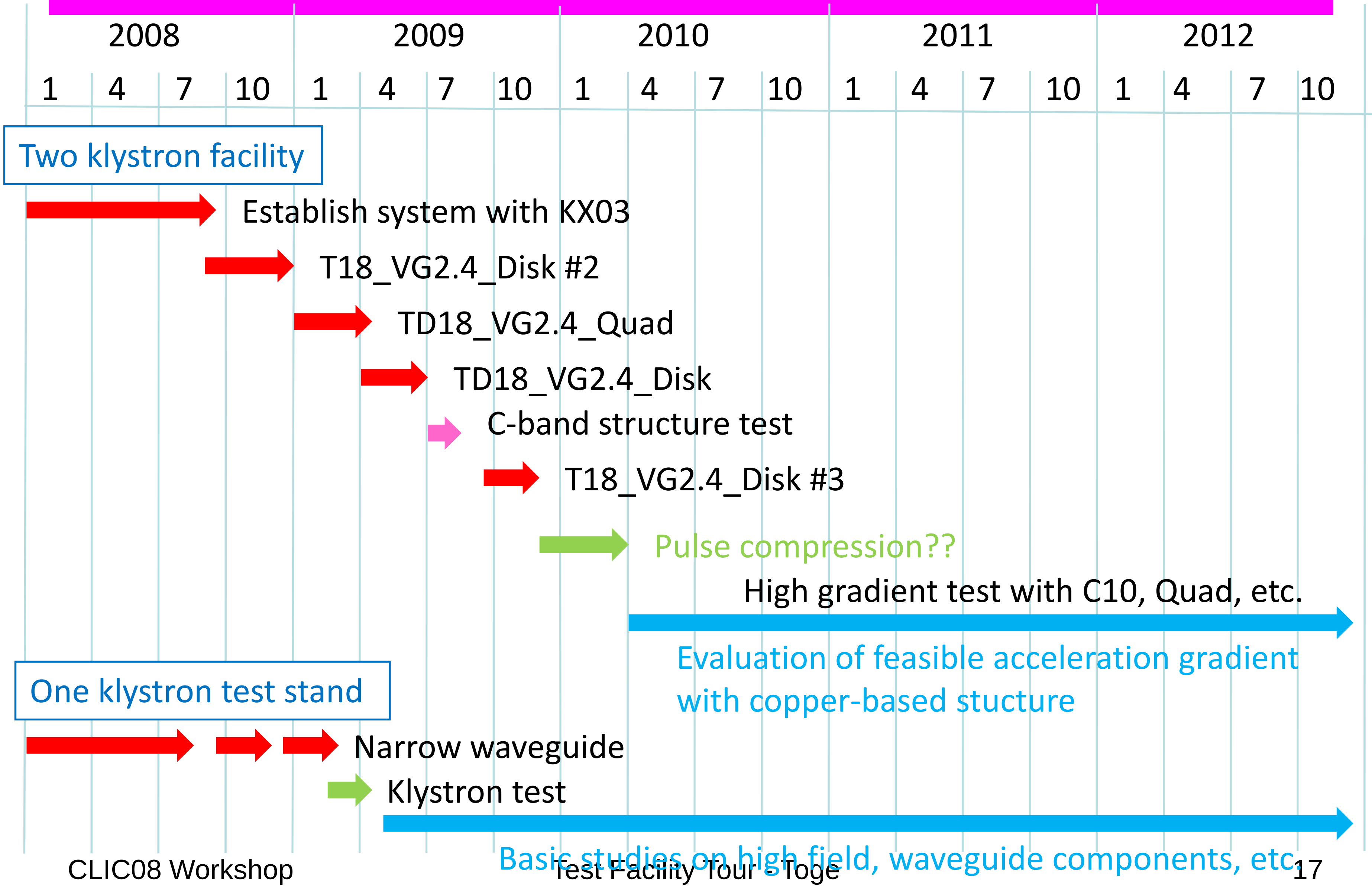


Inside shield room

NEXTEF – Research Programs

- Programs
  - High gradient tests in collaboration with CLIC (up to March 2011 in present MoU)
  - Pulse compression in 2009
  - Evaluation of feasible gradient with copper structure through long-term operation by 2012
  - Higher gradient studies beyond 2012
- Special points to note
  - NEXTEF shares the operations tech with the KEK injector linac. As a result, NEXTEF can run 24/7 when the KEK injector is in production operation.
- Relevance to
  - Cold-LC: None
  - Warm-LC: Close collaboration with CLIC structure developments and NEXTEF serves to get basic high gradient understanding and to develop components.

NEXTEF Research Plans



CesrTA

- CesrTA is
  - a reincarnation of Cornell's CESR storage ring which is being prepared as a test bed for addressing the electron cloud issues at LC damping rings.

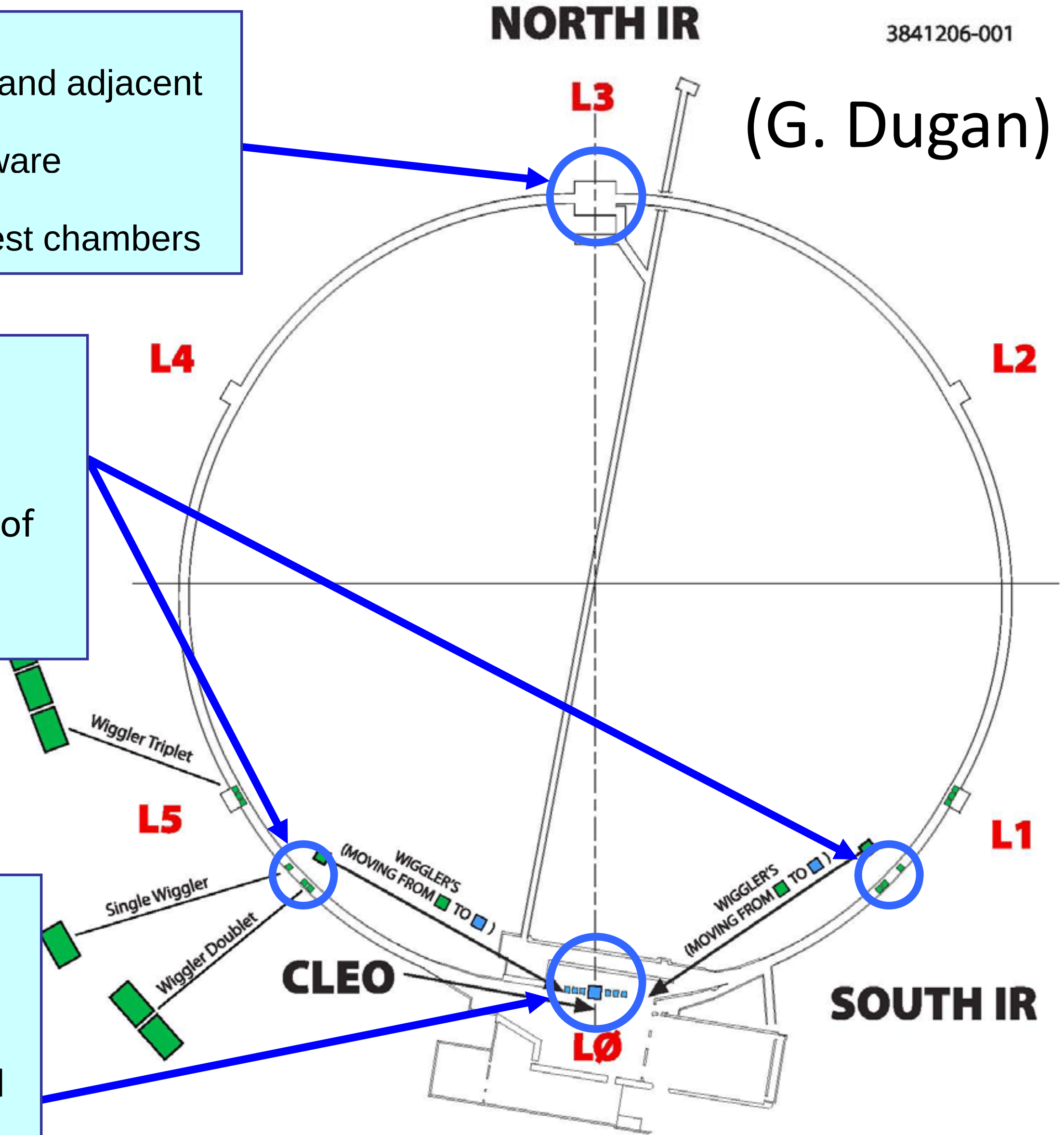
- CesrTA's missions are
  - To conduct a series beam experiments in 2008-2010 and conduct studies on
  - Growth of Electron Cloud and Mitigation Studies
    - Probe bunch configurations similar to ILC DR
    - Conduct unique studies in high field damping wigglers
  - Ultra Low Emittance Operation & Beam Dynamics Studies
    - Validate correction algorithms
    - Measure and maintain ultra low emittance beams
    - Characterize sources of emittance growth in ultra low emittance beams

      - ***Both with major relevance to all versions of LCs.***

CesrTA - Modifications

- L3 Straight Experimental area
  - Instrument large bore quadrupoles and adjacent drifts
  - Install of PEP-II experimental hardware (including chicane) in early 2009
  - Provide location for installation of test chambers

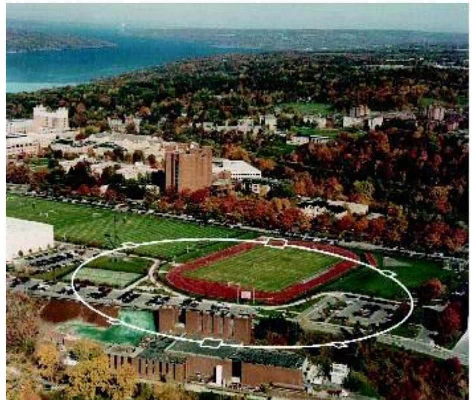
(G. Dugan)



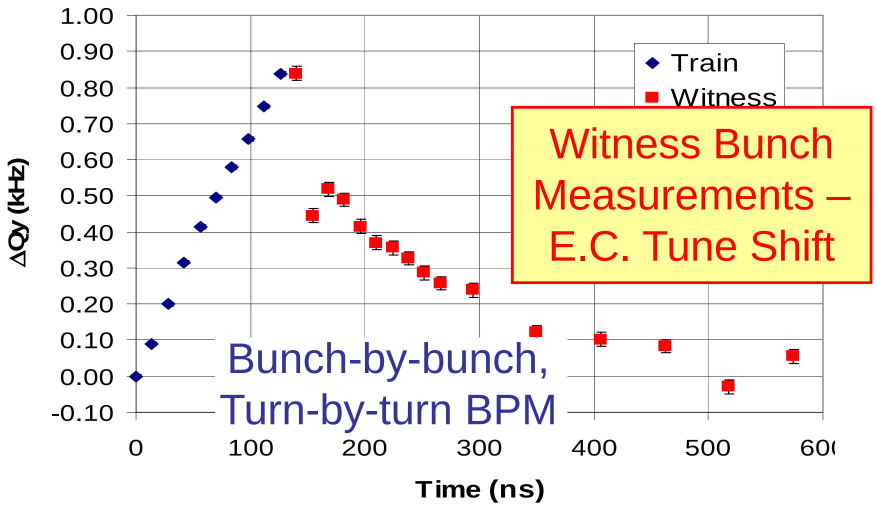
- Arc experimental areas
  - Instrument dipoles and adjacent drifts
  - Provide locations for installation of test chambers, in drifts where wigglers were removed.

- L0 Wiggler Experimental area
  - All wigglers in zero dispersion regions for low emittance
  - Instrumented wiggler straight and adjacent sections

CesrTA – Research Programs



0.75mA/bunch e+@1.9 GeV



Baseline Lattice

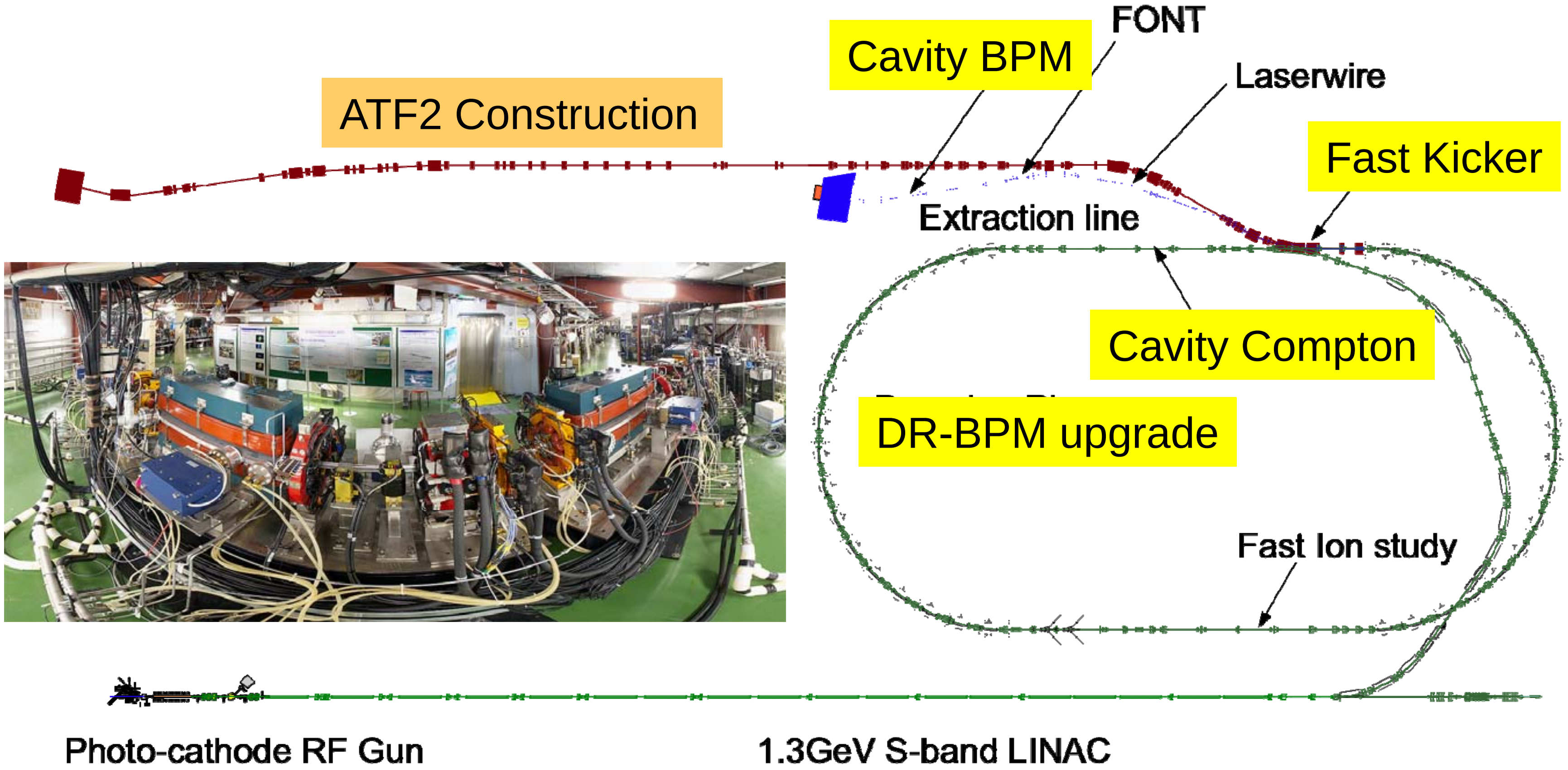
Parameter	Value
No. of Wigglers	12
Wiggler Field	2.1 T
Beam Energy	2.0 GeV*
ΔE/E	8.6 x 10^{-4}
ε_v (geo) target	<20 pm
ε_h (geo)	2.3 nm
Damping Time	47 ms
Bunch Spacing	4 ns
Bunch Length	9 mm

*CESR operating range is 1.5-5.5 GeV

ATF

- ATF is
  - An international collaboration around a test beam facility at KEK, to develop the technologies associated with production and control of ultra-low emittance beams that are needed for LCs.
- ATF missions
  - Advance the technologies needed for production and control of ultra-low emittance beams by constructing and operating an injector linac (max 1.54GeV) with multibunch-capable RF gun, a damping ring, and a beam extraction line.
  - Facilitate domestic and international collaboration of scientists in the relevant fields.
  - Offer a training ground for younger generation of scientists.

ATF - Layout


FONT
Cavity BPM
Laserwire
ATF2 Construction
Fast Kicker
Extraction line
Cavity Compton
DR-BPM upgrade
Fast Ion study
Photo-cathode RF Gun
1.3GeV S-band LINAC

ATF – Research Program

- Approximately 22 weeks (110 days) of operation / year.
  3 shifts / operation day.

- Research proposals are evaluated by Technical Board meetings before becoming part of the ATF program.

- A large number of research programs:
  - BPM upgrade
  - Cavity compton R/D
  - Multibeam operation
  - Fast beam extraction kicker
  - Cavity BPMs
  - ATF2 and related development

ATF – Remote Participation in Beam Studies

- NOT "remote control" but "remote participation" in beam data taking, analysis, interactions with on-site staff.
- Tools: Webex, Skype, Spy cameras in the ATF control room.
- Important for both ATF and ATF2.

This picture was taken at SLAC. Scientist at SLAC is interacting with the colleagues at KEK with displays showing the machine status and human activities.

IP-BPM

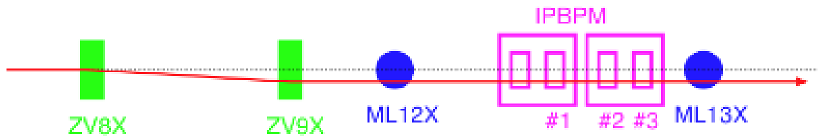
Beam test at ATF extraction line

@0.7x10^10 e/bunch, dynamic range: 5 um

Achieved resolution

8.72 +-0.28(stat) +-0.35(sys) nm

to 2nm → Stabilization of Temperature, Stabilization of extracted beam

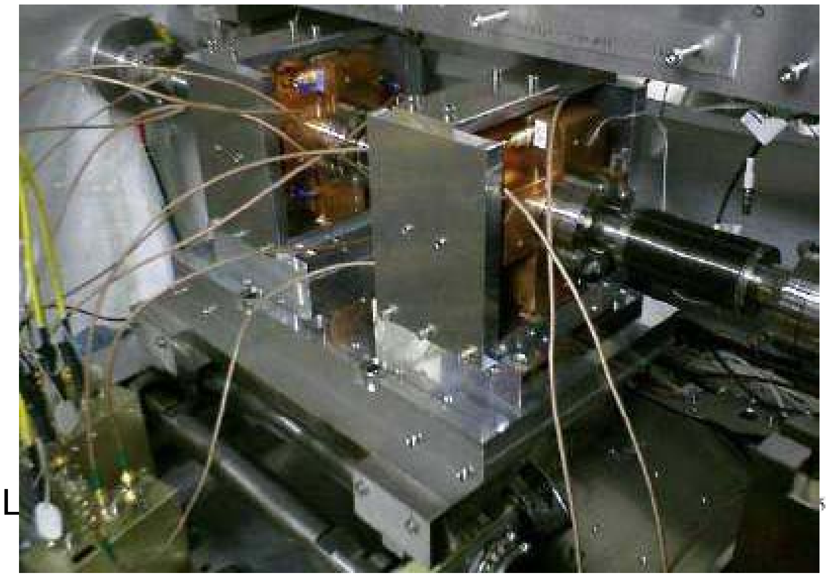


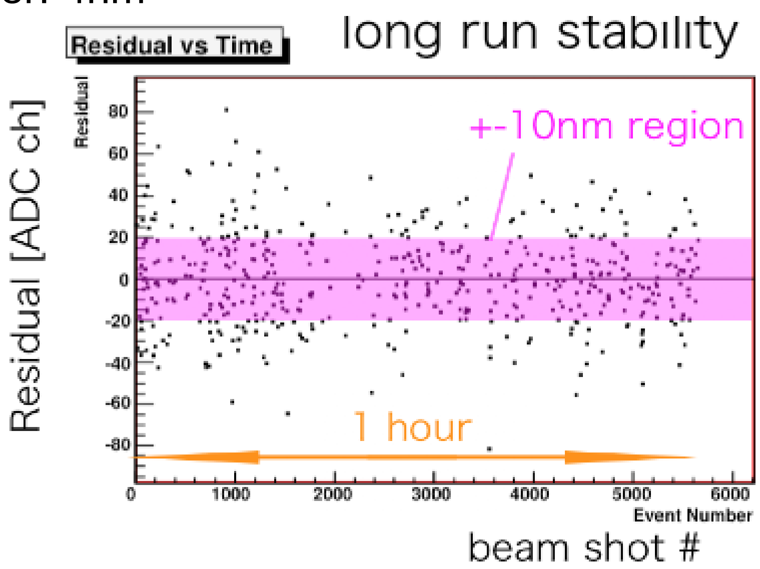
electronics noise limit:

5nm@0.7x10^10 e/bunch

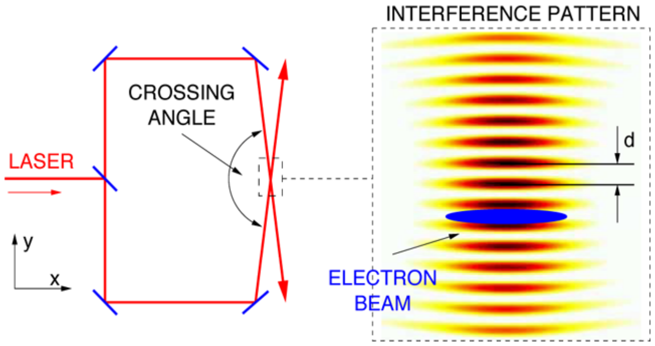
unknown noise: 7 nm

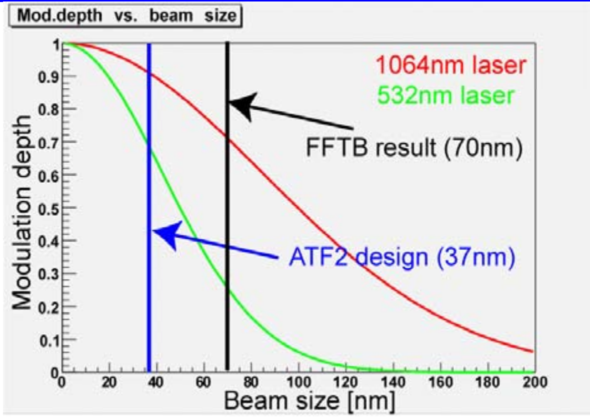
vibration measure by laser interferometer: 4nm

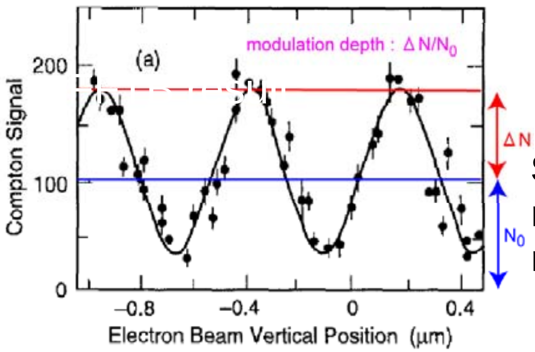




Beam size monitor for ATF2-IP (Tokyo Univ., KEK)







Shintake-monitor result in FFTB

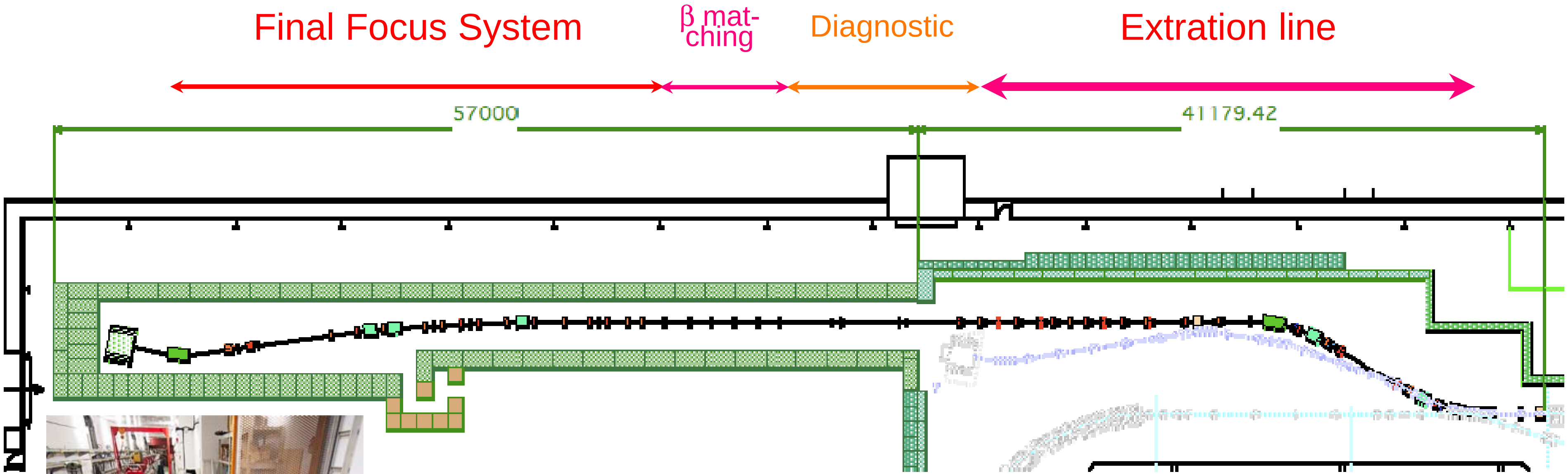
FFTB ~70nm -> ATF2 34nm
modification : Laser wavelength
fringe stabilization FB
new gamma detector

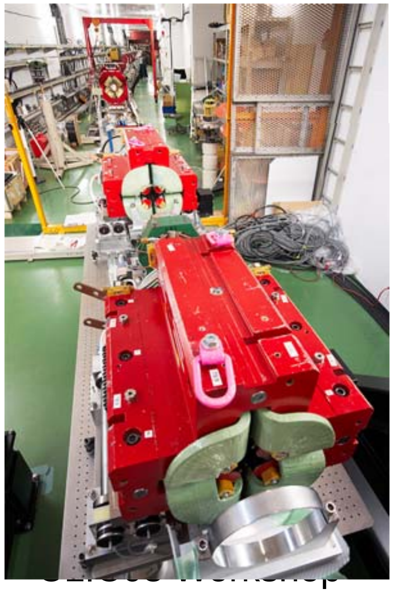
Installation at ATF2-IP (2008/5-)

ATF2

- ATF2 is
  - a final-focus test beamline, as extended from the beam extraction line of ATF damping ring at KEK.
- Two main missions
  - Achievement of 34nm beam size (vertical)
    - Demonstration of a new compact final focus design, proposed by P.Raimondi and A.Seryi in 2000,
    - Maintenance of the small beam size (Ref: several hours at the FFTB/SLAC)
  - Control of the beam position
    - Demonstration of beam orbit stabilization with nano-meter precision at IP (Ref: beam jitter at FFTB/SLAC was about 40nm.)
    - Establishment of beam jitter controlling technique at a nano-meter level with ILC-like beam (2008 -?)

ATF2 Layout


Final Focus System
β matching
Diagnostic
Extration line
57000
41179.42



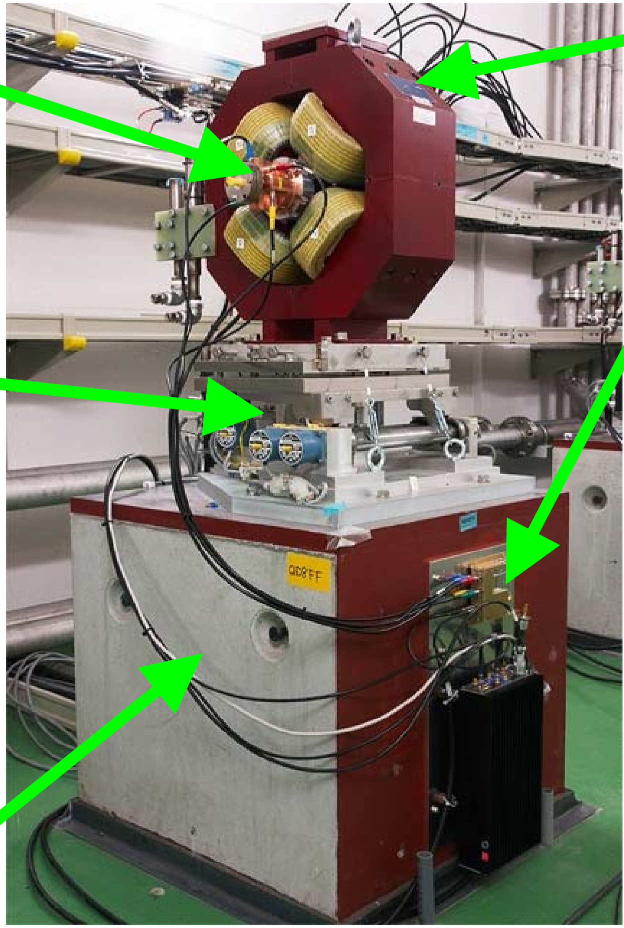
ATF2 – International Collaboration

QBPM
(Cavity BPM)
(KEK,PAL)

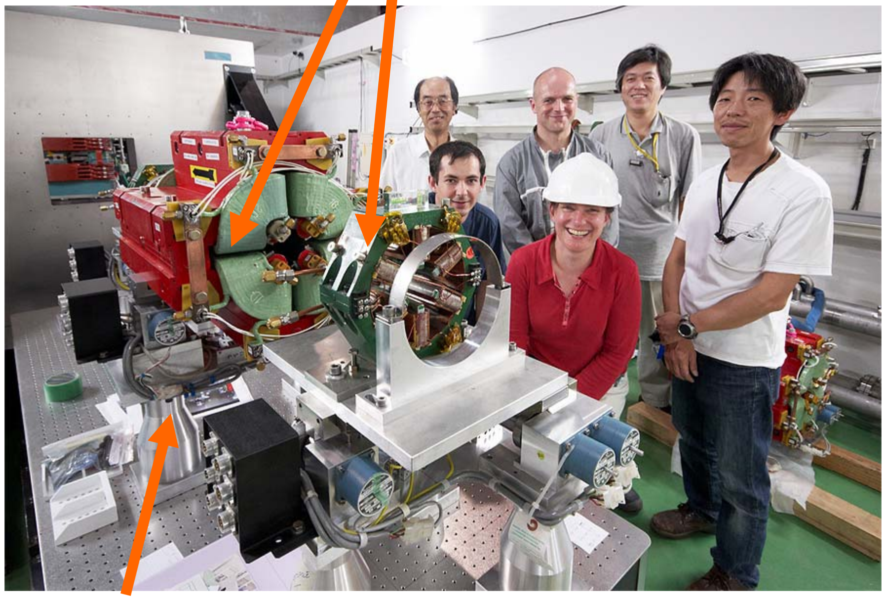
Q magnet
(KEK,SLAC,IHEP)

QBPM electronics (SLAC)

FFTB mover
(SLAC/MPI)



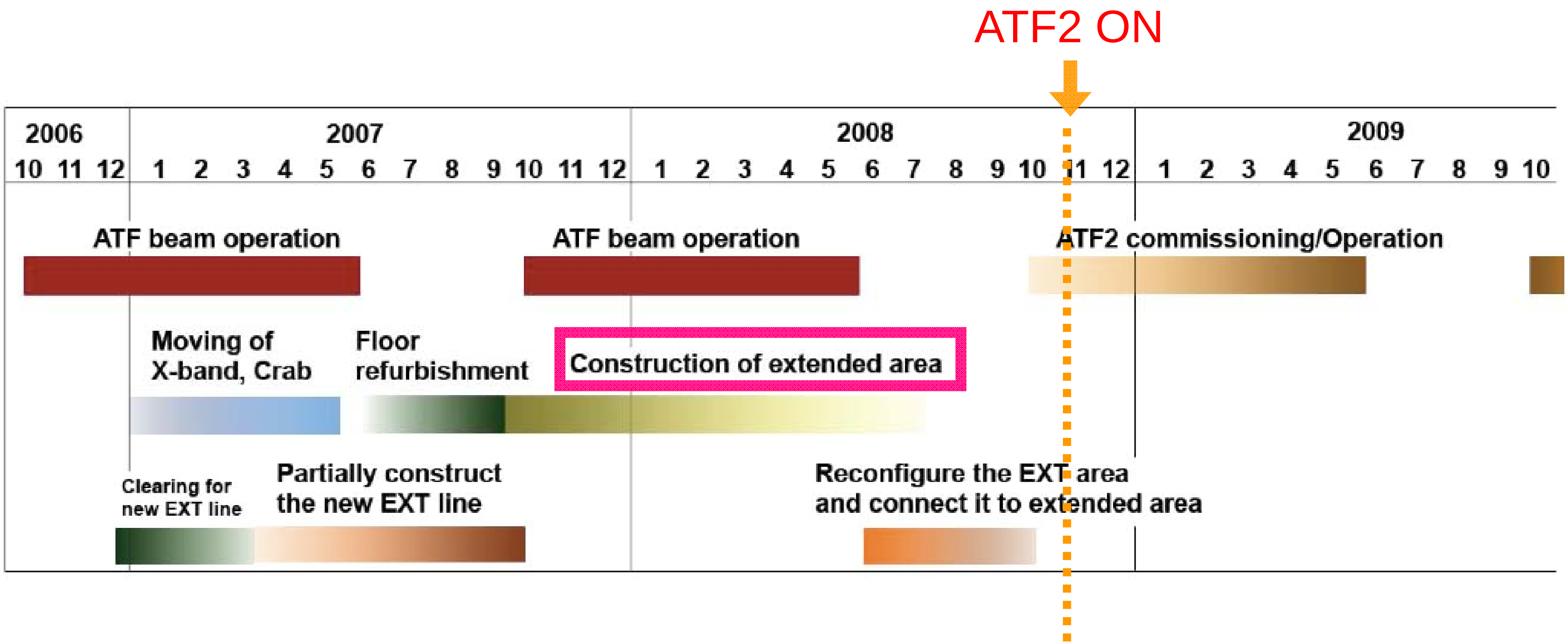
Final Q, SX and movers (SLAC/MPI)
QBPM for final Q (not shown, KNU)



Concrete Base Stand (KEK)

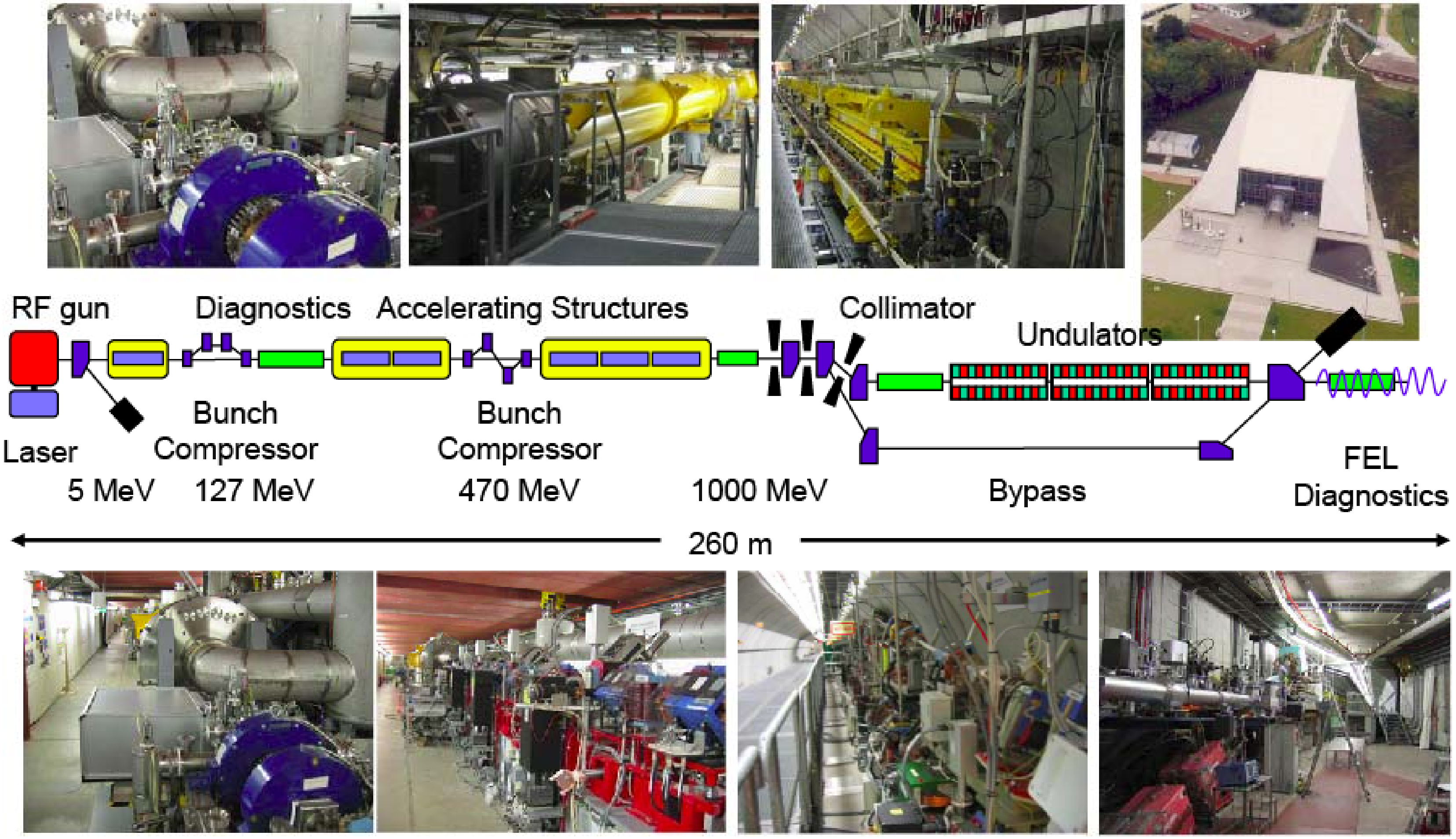
Support stand and table (LAPP)

ATF2 – Research Program



Commissioning to start in November 2008

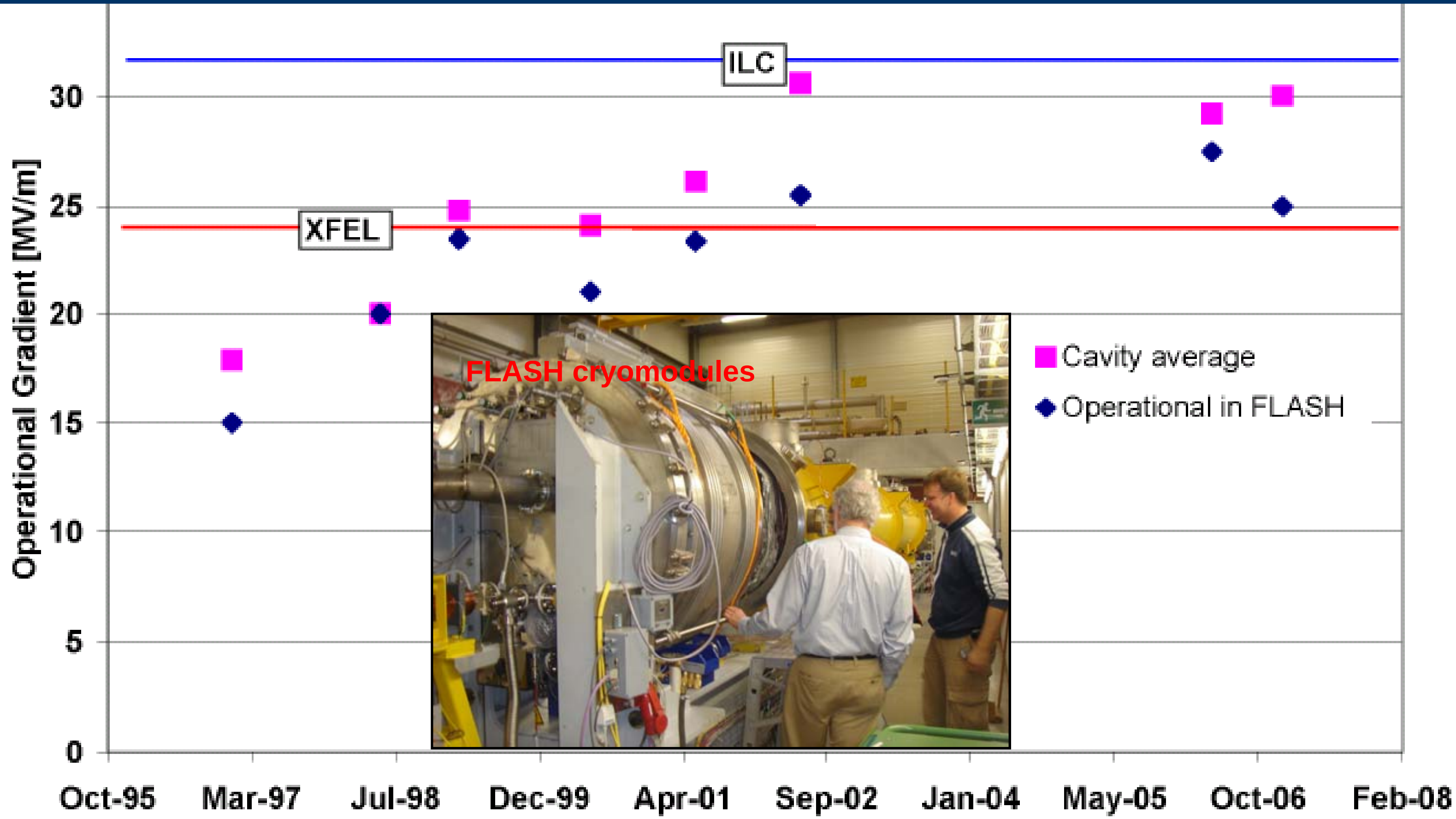
FLASH (former TTF)



FLASH

- FLASH (Free-electron LASer in Hamburg, formerly TTF) at DESY is a user facility in support of a wide range of applications of XUV radiation with energies in the 10 – 100 μJ range and pulses of 10-50fs. Top performance: 1GeV beam, 6.5nm W.L.
  - 16 projects, 200 scientists from 11 countries
- FLASH serves as a prototype for the European XFEL
  - Test bed for electron linacs based on superconducting RF, e.g. ILC
- Advanced diagnostics for linacs.
  - Bunch profile diagnostics (transverse and longitudinal)
  - Timing requirements exceeding those of CLIC
  - High intensity electron guns
- Slightly over 50% of the time is dedicated to user experiments, ~35% for FEL and accelerator studies, and ~13% for maintenance.
  - User and accelerator study time is allocated through a peer review process
  - Machine study proposals are welcomed

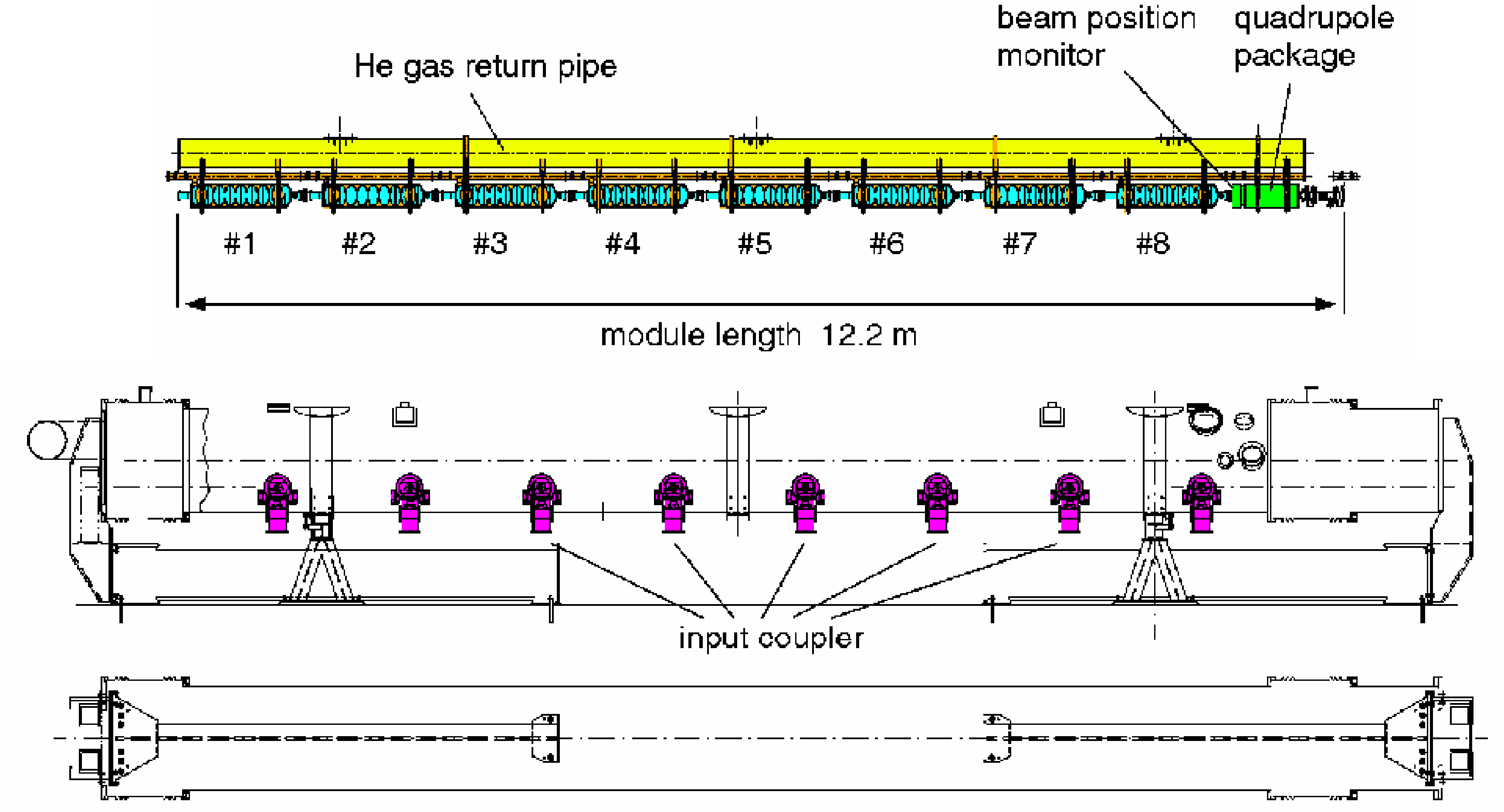
FLASH Cryomodules and Operation



Expected deliverables from FLASH and EuroXFEL for ILC -

Technical details of SCRF ; Hardware implementation; multi-national management, industrialization and operation

FLASH Cryomodules

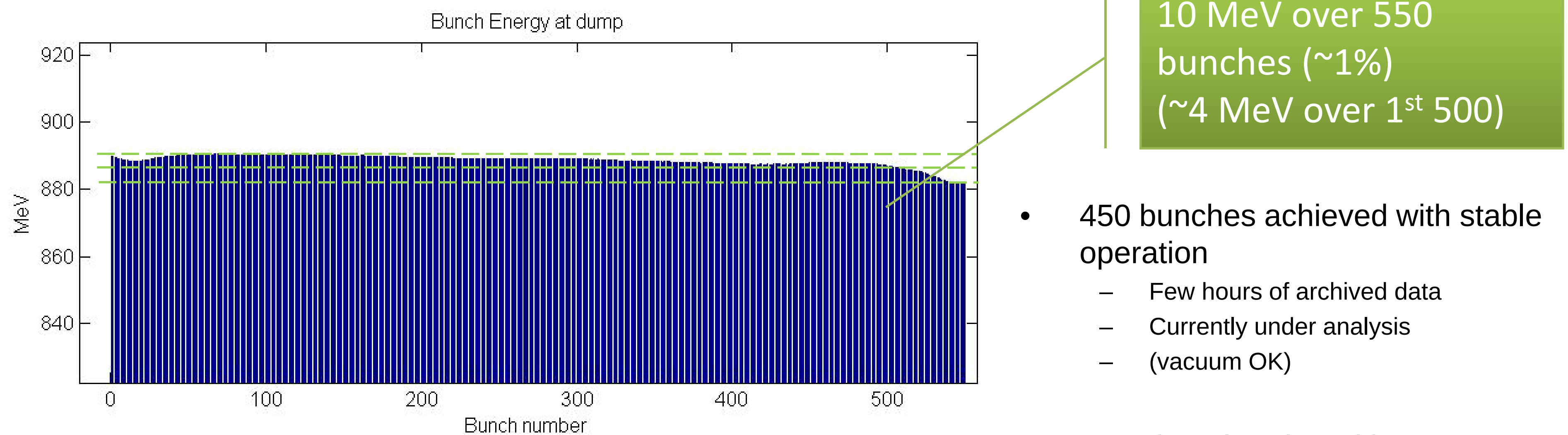


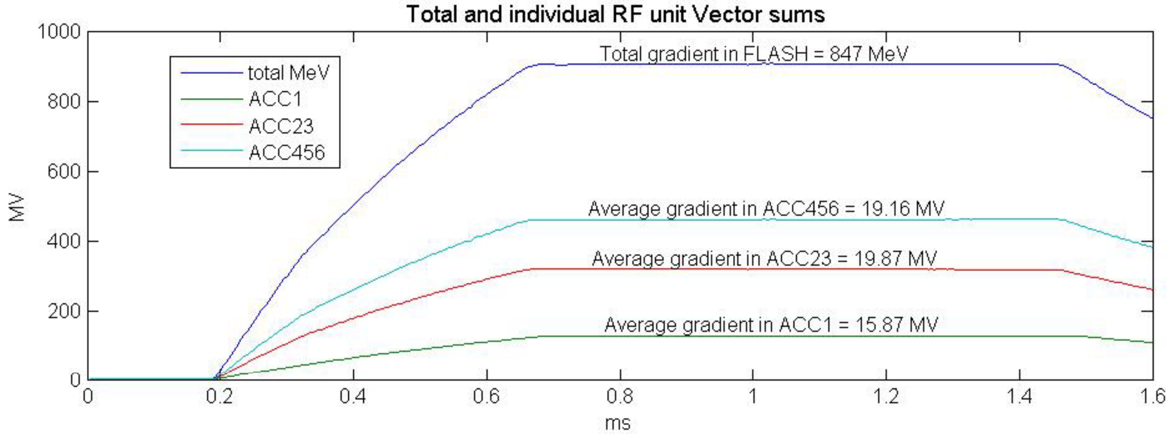
FLASH 9mA Program

- This is a program to demonstrate the operation of and to attain the experiences in running a SCRF-based linac system with the beam current of ~ 9mA (i.e. beam loading) that is compatible with ILC.
  - Run the cavities at highest gradients, full charge 3nC/bunch and 3000 bunches.
  - Test of the low-level RF (LLRF) controls and cavity stabilities under ILC operating conditions

- Results and plans:
  - Sep. 2008: Operation done with 550 bunches (3nC, 1MHz, 3mA). Beam stability observed ~ 0.1%.
  - Before FLASH 2009 shutdown: increase to 3MHz bunch repetition rate (9mA). Preparing a 2-week program (tbc) dedicated to 9mA studies

High Beam-Loading Long Pulse Operation at FLASH (Sept 08)





- 450 bunches achieved with stable operation
  - Few hours of archived data
  - Currently under analysis
  - (vacuum OK)
- Long bunch trains with ~2.5 nC per bunch:
  - 550 bunches at 1MHz
  - 300 bunches at 500KHz
  - 890 MeV linac energy
- All modules (RF) running with 800us flat-top and 1GeV total gradient

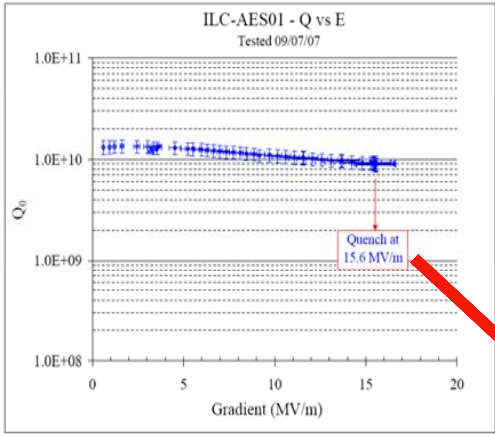
FNAL VTS and HTS

- FNAL VTS and HTS are
  - Test facilities (vertical tests, and horizontal tests), for ILC and Project X, for development and performance validation of L-band superconducting cavities.
  - VTS also supports 325MHz cavities.
  - HTS also supports 3.9GHz cavities.
- FNAL VTS, HTS missions
  - Facilitate development of L-band SC cavities and conduct performance validation (VTS,HTS).
  - Testing of related systems: RF control, tuning, microphonics, Lorentz-force detuning and thermal balance.

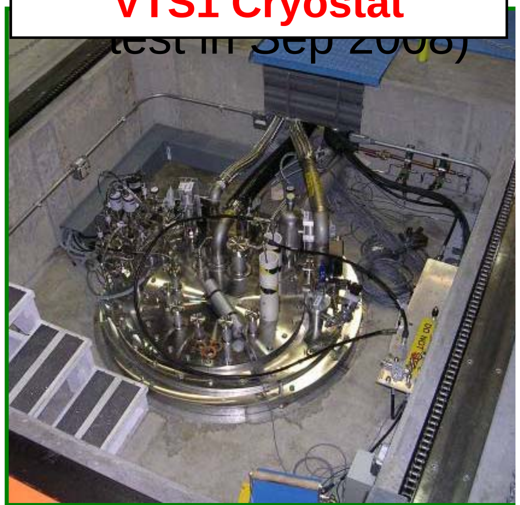
FNAL VTS

- Commissioned summer of 2007
  - 125 W, 1.8 K cryogenic plant
  - 325 and 1300 MHz RF systems
  - Capable of testing ~50 cavities/year
  - Ultimate capacity ~264 cavity tests/year (with addition of VTS 2&3 over next two years)
  - Temperature-mapping system under development (first single-cell T-mapping test in Sep 2008)

Nine-cell Tesla-style cavity

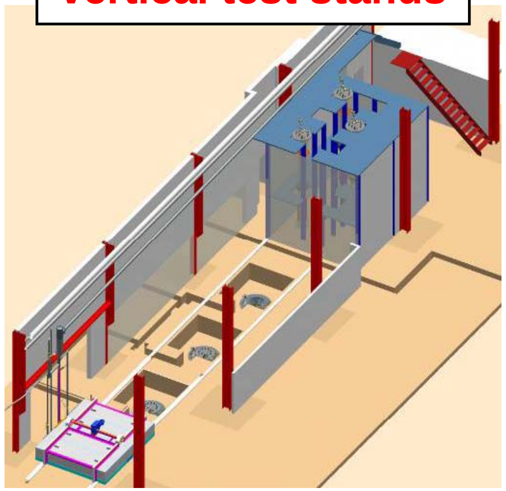


VTS1 Cryostat



Control Room

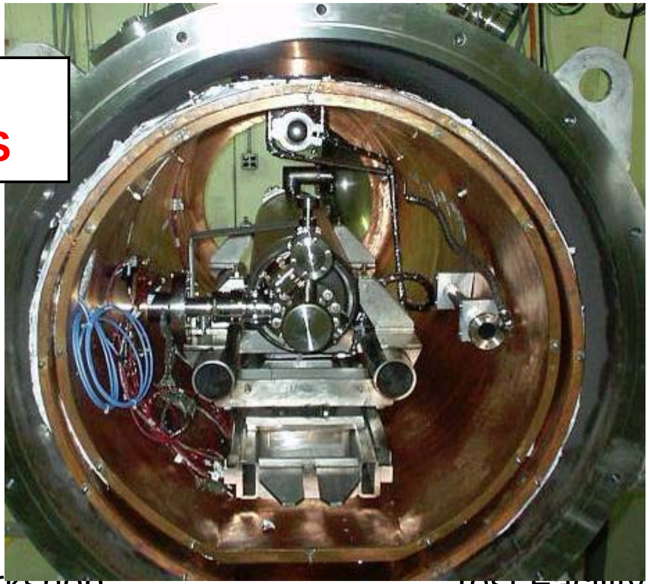
Layout for three vertical test stands



FNAL HTS

- The Fermilab HTS was designed for testing dressed 1.3 and 3.9 GHz elliptical cavities
  - Allows for tests of cavities equipped (dressed) with fundamental power coupler, HOM couplers, magnetic shielding and cavity tuning system
  - RF systems include klystrons at 1.3 GHz, 300 kW and 3.9 GHz, 80 kW
  - Supports testing of RF control system, tuning system, microphonics, Lorentz-force detuning, and thermal balance
  - Final cavity qualification prior to string assembly

First 1.3 GHz Cavity in HTS



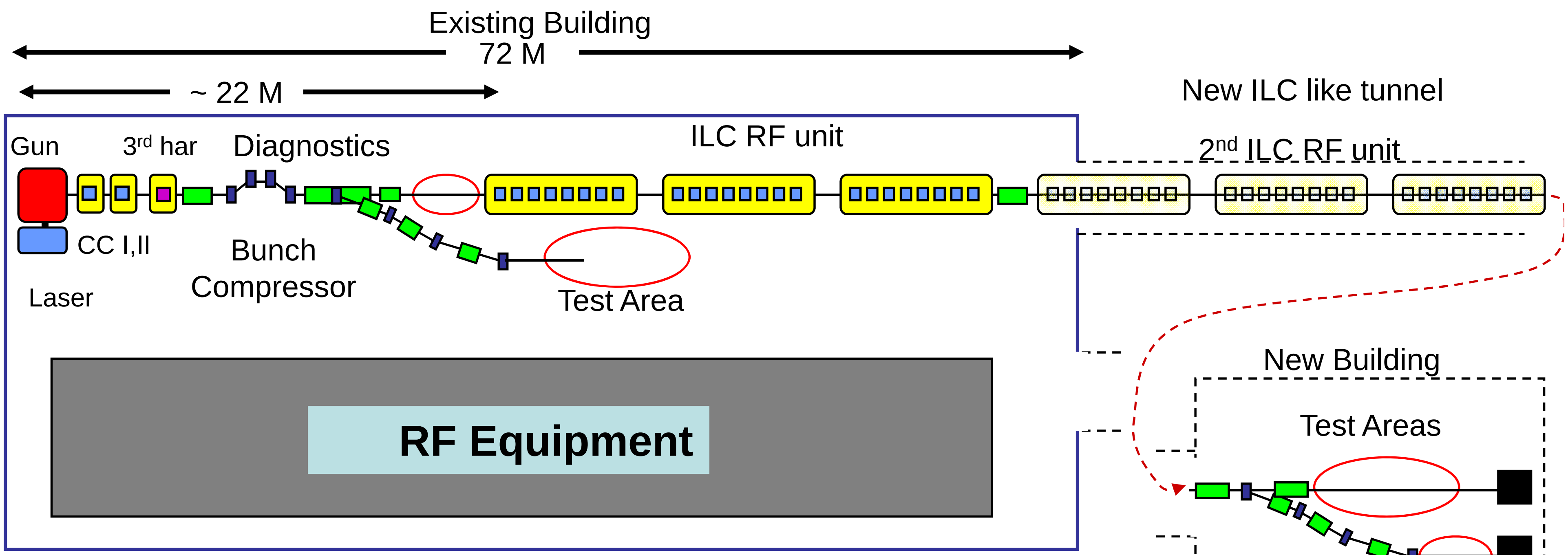
HTS Cryostat

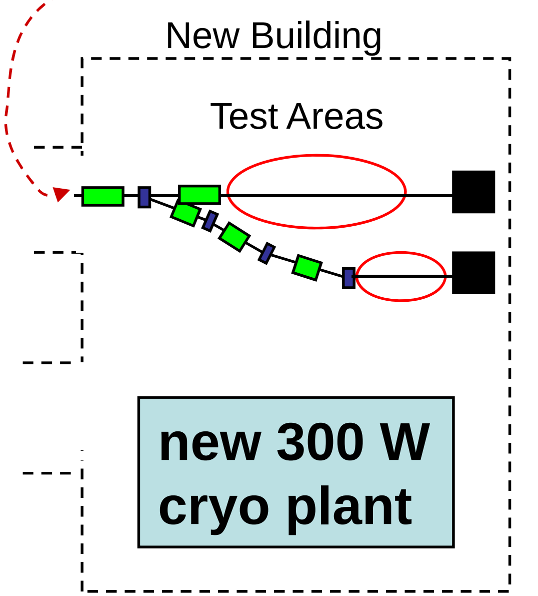
FNAL NML

- NML is a test facility at FNAL which is geared towards system-level validation of L-band superconducting linac systems for future accelerator projects including Project-X and ILC.

- NML missions are –
  - To build up, stepwise, the infrastructure that is needed to establish the expertise as a hosting laboratory in developing, constructing and operating major SRF-based linac systems.
  - In so doing, to build an ILC-style linac system with at least three cryomodules, with associated RF sources, control systems, cryogenics and beam sources.

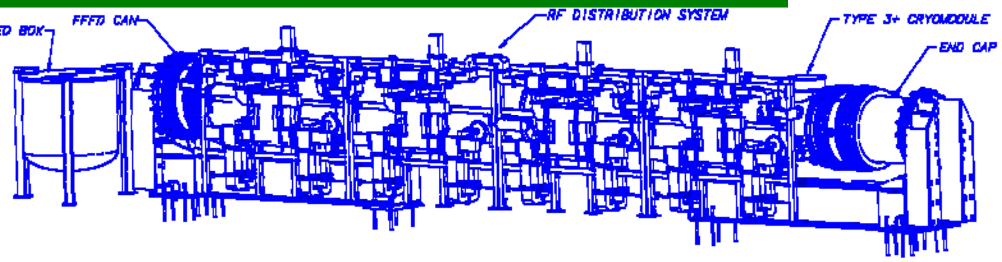
NML at FNAL

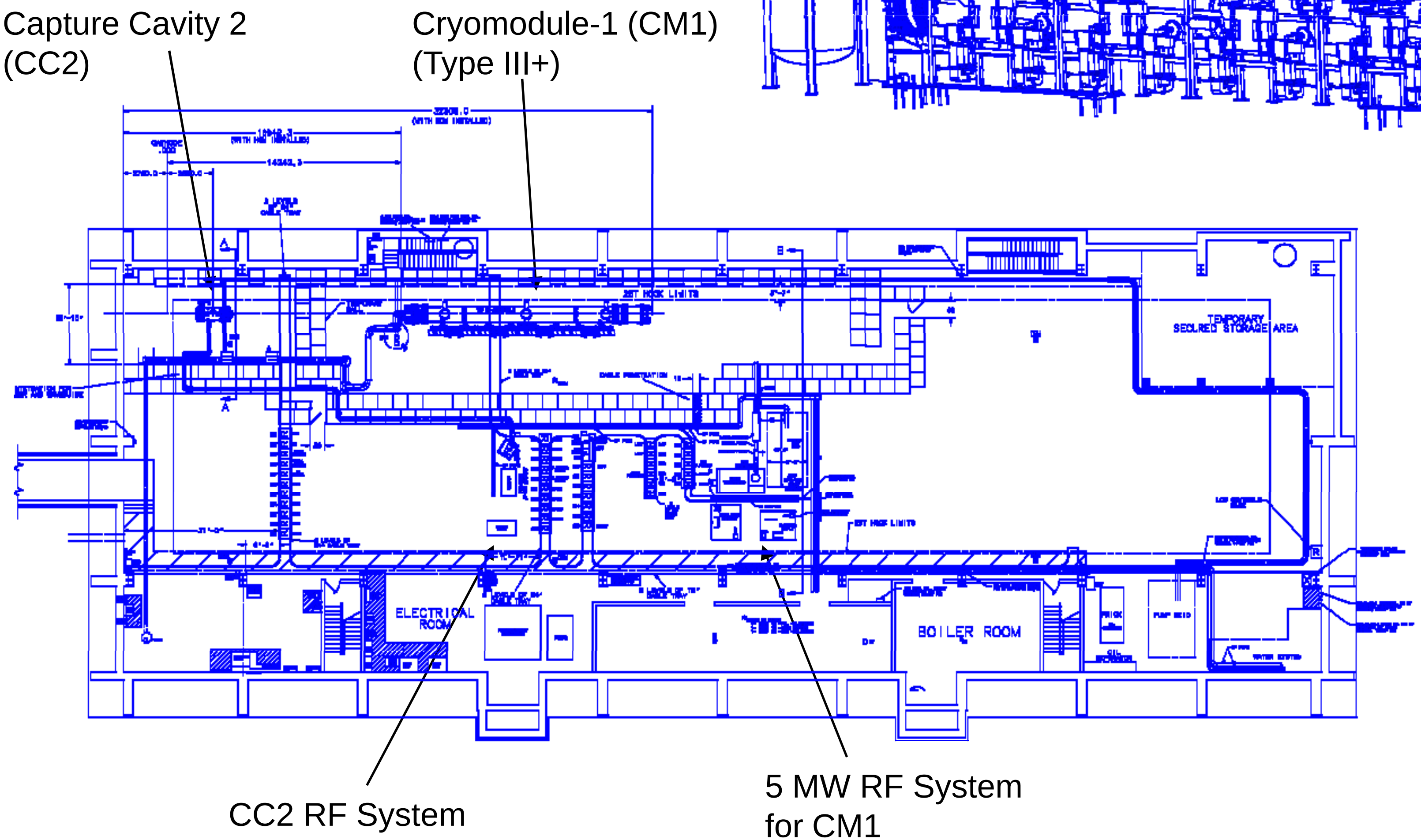




- **Overall Plan:** **Test ILC RF units**
  - **3 CM, Klystron, Modulator, LLRF**
  - **Move A0 Injector to provide ILC like beam**
- **New bldg:** **diagnostic, AARD, new cryo plant**
- **ILC Twin tunnel** **design to allow 2nd RF unit and to study tunnel layout and maintenance issues**

NML – Phase 1 Layout





NML – Current Status

- Install CM Support Girders (4/08)
- 1st Cryomodule Delivery to NML (8/08)
- Delivery of Waveguide from SLAC (9/08)
- Cryo System Component Delivery (10/08)
- Move CC2 to NML (10/08)
- Begin 1st Cryomodule RF Tests (Warm) (11/08)
- Commission Cryo Distrib. Sys. (CC2) (12/08)
- CM1 Ready for Cooldown (12/08)

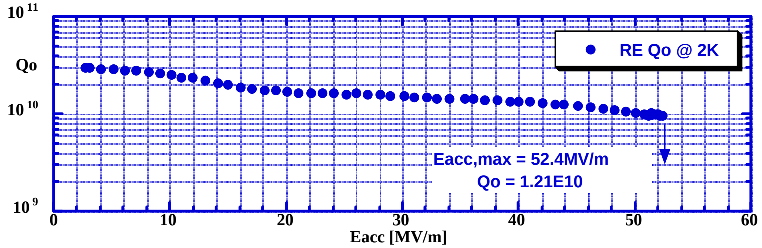
STF at KEK

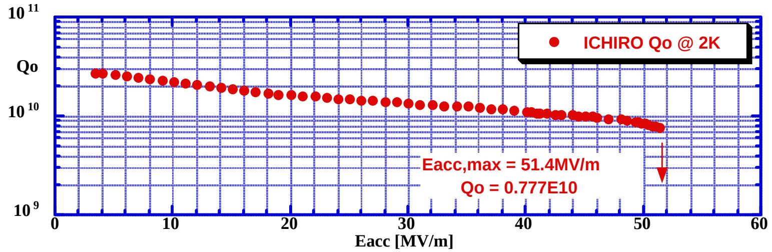
- STF is
  - A test accelerator facility at KEK to build and operate a test linac with high-gradient SC cavities, a prototype of the main linac system for ILC. It is associated with an ensemble of supporting facilities such as the cryogenics plant, clean rooms, electro-polishing and other surface treatment areas, and vertical test stands.

- STF missions are
  - Eventually build and operate at least one full unit of ILC main linac systems.
  - Facilitate a build-up of competitive expertise at KEK on the related technologies and serve as a regional center for the relevant activities.

STF in the recent past

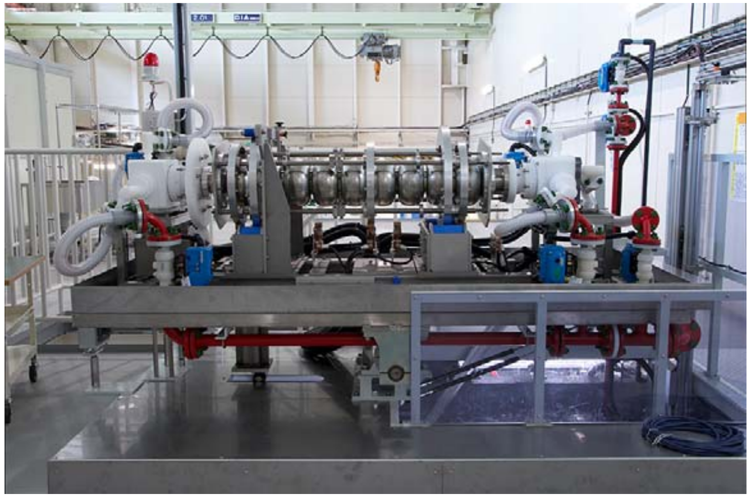
Single-cell cavities that recorded Eacc > 50MV/m





Horiz. Cryostat with 4 units of 9-cell cavities

STF – Associated Facilities

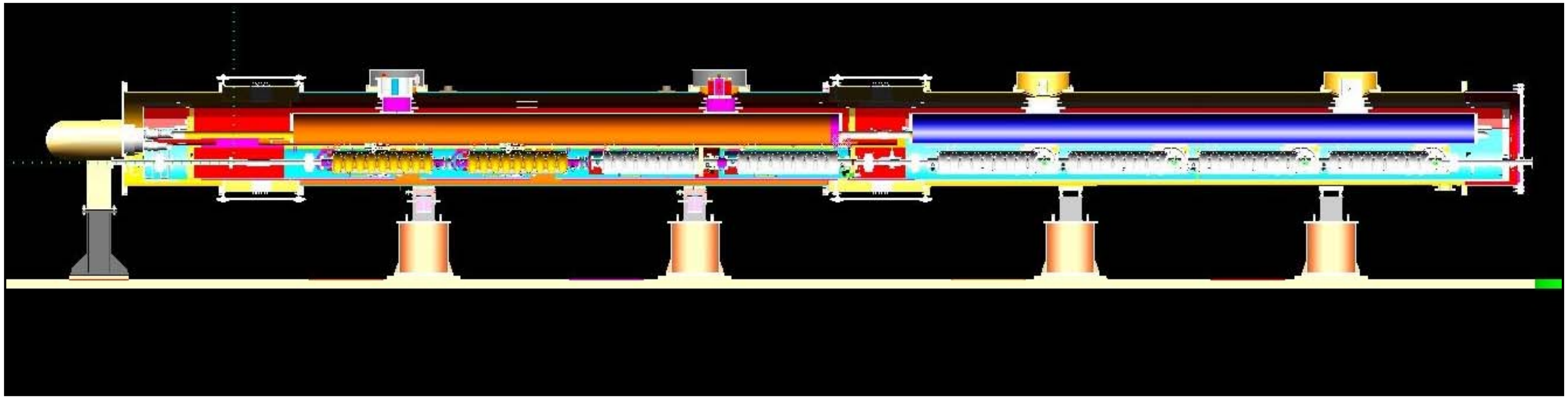


STF Plans

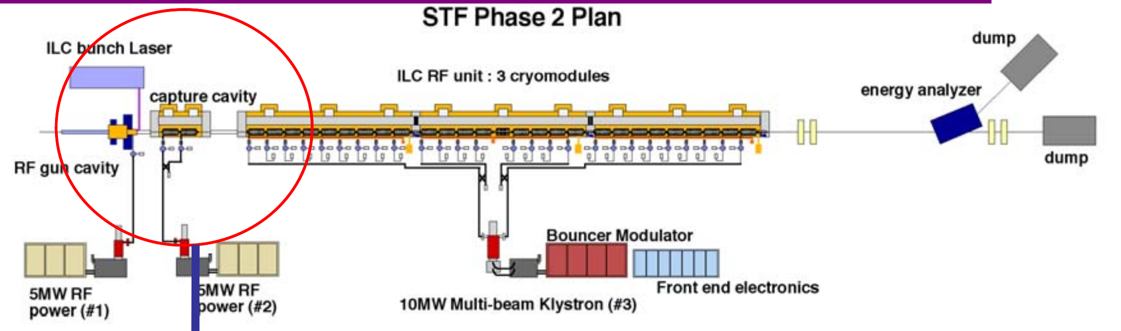
- 3 major subprojects following Phase-1

	S1Global	Quantum Beam	Phase-2
Significance	Plug-Compat.	SRF applications to X-ray sources	~ GDE S2
#Cavs	2+2+4	2	9+8+9
#CMs	2	1	1+1+1
Beam?	No	Yes	Yes
International collab?	Yes	Maybe No	Maybe No?
Operation	2010/6-12	2011/10-2012/7	2013/1? -

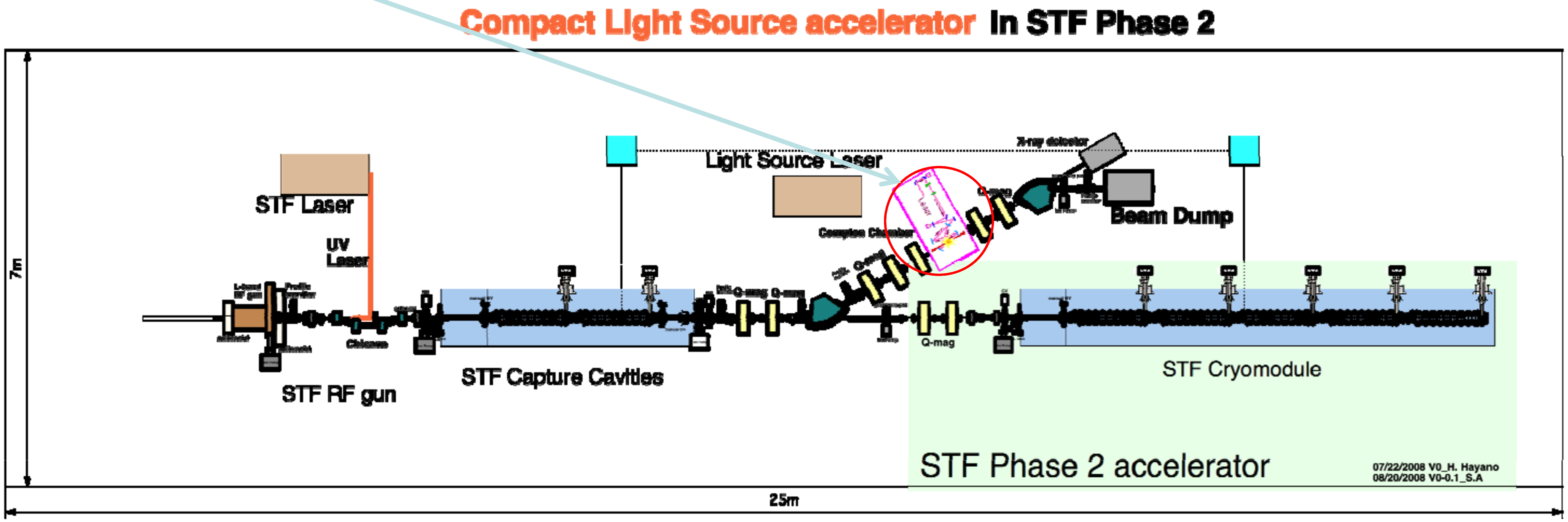
- Motivations at the R/D stage and the construction
- S1-global = Exercise of Plug compatibility by an internat'l collaboration
  - 2009-2010
  - EU: 2cav + NA: 2 cav + Asian 4 cav
  - CM design by EU (Frascati)



SRF-based X-ray sources with the “Quantum Beam” Grant



Quantum Beam Accelerator
X-ray generation experiment in 2012



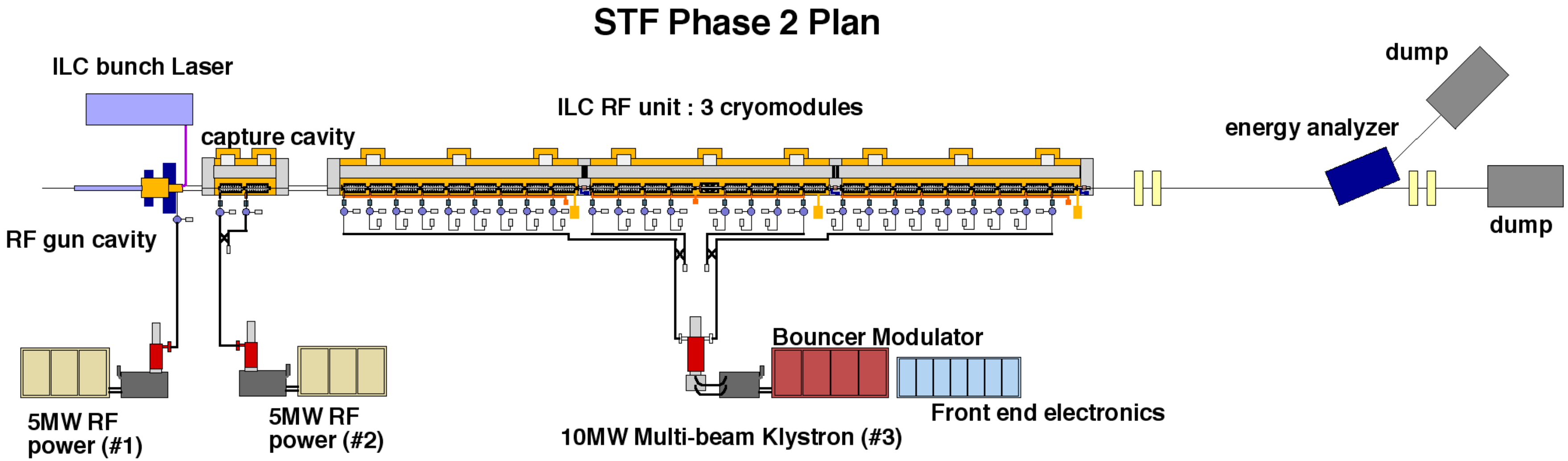
STF Project Phase-2

Cavities: 2 capture cavities in one short cryostat with essentially the same cross sectional arrangement as ILC standard modules.

+ 26 cavities (in ILC-style full-length cryomodules x 3)

RF source : 10MW MBK + bouncer modulator + Linear PDS + ATCA base LLRF

e- beam : FNAL RFgun + IAP laser : 3.2nC x 2625 bunches → 9mA, 5Hz, Acceleration up to 850MeV



CLIC-Related Summary

SYSTEMS (level n)		Critical parameters	Crucial design choice or fesibility	Performance issue	Cost issue	Relevant Facilities
Structures	<u>Main beam acceleration structures</u> Demonstrate nominal CLIC structures with damping features at the design gradient, with design pulse length and breakdown rate .	100 MV/m 240 ns 3·10-7 BR/(pulse*m)	X	X	X	CTF2&3 (2005-2010) Test Stand (2009-2010) SLAC/NLCTA SLAC/ASTA KEK/NEXTEF
Structures	<u>Decelerator structures</u> Demonstrate nominal PETS with damping features at design power, with design pulse length, breakdown rate on/off capability	136 MW 240 ns	X		X	CTF3 (2005-2010) CTF3/TBTS (2008-2010) CTF3/TBL (2009-2010) SLAC ASTA
Drive Beam	<u>Validation of drive Beam</u> - production - phase stability , potential feedbacks - MPS appropriate for beam power	0.2 degrees phase stability at 12 GHz	X	X		CTF3 (2005-2010) CTF3/TBL (2009-2010) X-FEL LCLS
Two Bea m	Test of a relevant linac sub-unit with both beams	NA	X			CTF3/TBTS (2008-2010)
Beam physics	<u>Ultra-low emittances</u> - Generation of low-emittances (damping rings)	Hor:500 nradm Vert: 5 nradm		X		ATF (2008-10): 3000/12 CESRTA:Electron Cloud NSLSII: Hor 2000nradm SLS: Vert 10nm
Beam physics	- Preservation of low emittances (main linac + RTML)	Absolute blow-up Hor: 160nradm Vert: 15 nradm	X	X		Beam simulations LCLS SCSS
Beam physics	- Beam focusing to small dimensions (BDS)	Hor: 40 nm Vert: 1 nm		X		ATF2 (2006-2012) Hor: 200 nm Vert: 36 (20) nm
Stabilization	Main Linac and BDS Stabilization	Main Linac : 1 nm vert (>1 Hz) BDS: 0.15…1 nm vert (>4 Hz) depending on implementation of final doublet girder	X	X	X	CESRTA ATF2

ILC-Related Summary

Test Facility	Deliverable	Date
Optics and stabilisation demonstrations:		
ATF	Generation of 1 pm-rad low emittance beam	2009
ATF-2	Demo. of compact Final Focus optics (design demagnification, resulting in a nominal 35 nm beam size at focal point).	2010
	Demo. of prototype SC and PM final doublet magnets	2012
	Stabilisation of 35 nm beam over various time scales.	2012
Linac high-gradient operation and system demonstrations:		
TTF/FLASH	Full 9 mA, 1 GeV, high-repetition rate operation	2009
STF & ILCTA-NML	Cavity-string test within one cryomodule (S1 and S1-global)	2010
	Cryomodule-string test with one RF Unit with beam (S2)	2012
Electron cloud mitigation studies:		
CESR-TA	Re-config. (re-build) of CESR as low-emittance e-cloud test facility. First meas. of e-cloud build-up using instrumented sections in dipoles and drifts sections (large emittance).	2008
	Achieve lower emittance beams. Meas. of e-cloud build up in wiggler chambers.	2009
	[illegible]	

Summary

- Obvious commonality
  - Test facilities to address issues with sources, damping rings, beam delivery systems, beam dynamics.
- Not-obvious but definite commonality
  - International sharing of design efforts, component construction + testing and facility operation.
  - Internationally shared ways of – documentation, hardware interfacing, record logging, archiving.
- Cultivation of the culture that is needed for LC construction through,
  - cooperative R&D and project execution.

STOP HERE